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**United States Air Force
Precision Engagement
against Mobile Targets
*Is Man In or Out?***

KEITH J. KOSAN, MAJOR, USAF
School of Advanced Airpower Studies

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Abstract

Recent airpower operations revealed a deficiency in the United States Air Force's (USAF) ability to precisely attack mobile targets at standoff ranges with minimal collateral damage. Future airpower operations will be executed in politically sensitive strategic environments and thus will require the ability to precisely destroy mobile targets that may have been strategically placed by an adversary in areas with a high risk of collateral damage. Current air-to-ground guided weapon systems, including man-in-the-loop guidance weapon systems, have limited "collateral reduction" capabilities; and future autonomous precision standoff weapon systems may increase the risk and uncertainty associated with collateral damage due to technology limitations. The acquisition of a precision standoff man-in-the-loop weapon system through the modification of current weapon systems or the acquisition of a new weapon system may provide the USAF a critically needed air-to-ground capability against mobile targets in a high-risk collateral damage environment.

About the Author

Maj Keith J. Kosan was commissioned through the Reserve Officer Training Corps, Wright State University, Dayton, Ohio, in 1985. Graduating from Undergraduate Navigator Training and Electronic Warfare Officer Training in 1986, he went on to fly EF-111s as an instructor electronic warfare officer (EWO). Following an assignment as an instructor navigator and international training flight commander, he returned to the EF-111 as an operational test and evaluation EWO. He was subsequently selected to attend the USAF's Test Pilot School. After completion, he performed weapons development on the F-15E while serving as a developmental test and evaluation weapon systems operator, flight commander, and assistant operations officer. Major Kosan is a senior navigator with over 1,800 hours in 34 different aircraft. He has a bachelor's degree in Biomedical Engineering from Wright State University and a master's degree in Project and Systems Management from Golden Gate University, San Francisco, California. In July 2000, Major Kosan was assigned to the Secretary of the Air Force, Acquisition, Special Programs. Major Kosan is happily married to the former Cynthia Schattel and has two children, Katie and Adam.

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I would like to dedicate this work to my father and acknowledge his professionalism and courage in flying combat missions over the Ho Chi Minh Trail during the Vietnam War, in which he faced many of the issues and challenges addressed in this paper.

Most importantly, I would like to express my sincere appreciation to my wife Cindy, my daughter Katie, and my son Adam for their love, patience, and understanding in the completion of this paper. I could not have completed this work without their support and encouragement. I will forever hear my daughter's sweet voice ask, "Daddy, are you working on your big paper or one of your little papers?" and the welcome calls for a study break from my son as he would ask, "Daddy can you play with me?"

Chapter 1

Introduction

The fundamental problem of managing military research and development is that uncertainty about the enemy and about the costs and benefits of new technologies make it impossible to identify the single best route to innovation.

—Stephen P. Rosen

Stephen Rosen's statement identifies one of the most challenging problems facing political and military leaders today. In an era of uncertainty, which includes a diversity of potential threats and military operations, what is the "single best route" in the area of military innovation to translate limited research and development (R&D) resources into capabilities to deal with current or potential threats to the United States (US) and its allies? Currently, the United States Air Force (USAF) is embracing a recent military technological innovation—autonomous guided air-to-ground weapons—while reducing or eliminating other guided air-to-ground weapons. In light of recent airpower operations and the uncertainty of future security challenges, military operations, and threats: Is this R&D strategy the single best route for the USAF in the area of air-to-ground weapons?

Problem Background and Significance

Precision engagement has been the Holy Grail of airpower visionaries, theorists, operators, and technologists since the inception of airpower. Improvement in airpower precision engagement has been remarkable. Airpower operations during Operation Desert Storm vindicated the USAF's armament R&D approach to precision engagement and demonstrated the service's ability to attack and destroy fixed strategic targets precisely, effectively, and with minimal collateral damage. However, recent military operations have shown a need for precision conventional strike (PCS) capabilities against mobile targets.¹

The success of airpower operations during Allied Force, a North Atlantic Treaty Organization (NATO) military operation against Serbian atrocities in Kosovo, also appears to validate the USAF's R&D strategy over the previous decade. In PCS operations, the USAF's autonomous weapons greatly increased airpower capabilities and effectiveness. Joint direct attack munitions (JDAM) and conventional air-launched cruise missiles (CALCM) demonstrated the stunning capabilities of USAF precision engagement. However, there were deficiencies and limitations associated with current USAF PCS capabilities.

Airpower precision engagement in Allied Force revealed a deficiency in airpower's ability to precisely attack mobile targets and fielded forces in a complex political-military collateral damage sensitive environment. The inability to identify and precisely destroy military targets in close proximity of noncombatants was the main cause of this deficiency. This problem, coupled with the political and military leadership's desire to minimize collateral damage and Serbia's exploitation of this sensitivity, limited airpower's ability to attack Serbian military forces in Kosovo. The *Joint Statement on the Kosovo After Action Review* stated, "As expected, attacks on mobile targets proved more problematic than attacks against fixed targets . . . concerns for limiting collateral damage also constrained us in some circumstances from attacks on possible ground force targets."²

This shortfall in airpower PCS capabilities is an obvious vulnerability. Serbian leaders exploited this shortfall through an asymmetric military strategy that focused on the use of terror and attempted to use the premium NATO placed on minimizing civilian casualties and collateral damage. Serbian tactics included exploiting NATO political concerns about target selection, collateral damage, and conducting military operations against enemy forces intermingled with civilian refugees.

Political and military authorities' attitudes towards collateral damage influence PCS operations and therefore should also influence USAF PCS weapons research, development, and acquisition. Airpower PCS operations in high-risk collateral damage environments can have a profound strategic implication for national interests and military operations. Political and military leaders will therefore demand accountability in airpower PCS operations. In this regard it must be asked, Should a human be involved in target selection and weapon delivery decisions that could result in intentional or unintentional death and destruction, or will technological advances in target identification and weapon guidance provide an "acceptable accountability" for autonomous systems?

The USAF appears to be supporting "technology accountability" as it develops more autonomous guided air-to-ground weapons, while reducing and eliminating other guided air-to-ground weapons. Specifically, the USAF's air-to-ground munitions road map focuses on autonomous weapons while demonstrating little interest in man-in-the-loop (MITL) weapons. Given the uncertainty of future conflicts, should the USAF pursue this particular military innovation strategy? An analysis of the current strategic environment, US political guidance, US military doctrine, recent airpower operations, present USAF guided air-to-ground capabilities, and the USAF's guided weapons acquisition strategy reveals the USAF may be reducing airpower's inherent flexibility by focusing on autonomous weapon systems while eliminating MITL systems. This reduction in flexibility could diminish the USAF's ability to deal with uncertainty.

Assumptions

This analysis is based on four assumptions. First, American military intervention will occur not only for events that directly affect US national security interests or those of its allies but for events that attract major media coverage or those events that have created public or political sympathy in the United States. Second, airpower will continue to grow in importance in US military actions. Third, other than in total war for national survival, the minimization of casualties—friendly and adversarial—and collateral damage will drive military operations and rules of engagement (ROE) in future conflicts. Fourth, the current military drawdown is not a short-term condition, and budget funding will not fully meet stated US military requirements.

Methodology

This analysis will not only address the technological issues but the international, national, and military strategic environmental issues that may affect technology. It will, however, address only air-to-ground aircraft and weapon capabilities in regards to technological issues and does not address employment tactics or personnel training issues. It is understood that shortfalls and limitations in PCS operations against mobile targets may also be due to or overcome by weapon employment tactics or aircrew training; however, this analysis focuses on only USAF's research, development, and acquisition strategy in regards to PCS operations against mobile targets.

Scope

US military airpower capabilities are not limited to the USAF but include US Navy (USN), US Army, US Marines, and allied or coalition airpower capabilities. Each service has air-to-ground capabilities that are critical to successful airpower operations; however, this analysis focuses on the USAF's air-to-ground capabilities and its role in PCS operations. This analysis will include information on USN R&D in air-to-ground munitions against mobile tactical targets due to a direct joint analysis of alternatives (JAOA), but it will not address USN air-to-ground capabilities or limitations. As the predominate force in US airpower, this analysis will focus on USAF's PCS capabilities against mobile targets and its future research, development, and acquisition strategy in this area.

Many of the issues addressed in this analysis are applicable to and influenced by unmanned aerial vehicle (UAV) developments and operations; however, this analysis focuses on USAF munition precision engagement capabilities and does not perform an in-depth analysis of aerial platform precision engagement capabilities. Additionally, in relation to UAV opera-

tions, this analysis addresses MITL precision guidance from the air; however, many of the conclusions and recommendations of this analysis are applicable to MITL precision engagement operations from the ground.

Format

This analysis of the USAF's research, development, and acquisition strategy in support of PCS operations against mobile tactical targets uses a five-part approach. Chapter 2 addresses the characteristics of future military conflicts and airpower operations to include international and national strategic environment, national political guidance, US military doctrine, recent airpower operations, and the challenges and requirements these issues create for USAF PCS operations. The next part of this analysis, chapter 3, looks at current USAF weapon systems and their capabilities and limitations in the identification and destruction of mobile targets. Chapter 4 evaluates the USAF's present armament R&D strategy in regards to PCS capabilities against mobile targets. Chapter 5 discloses and addresses legal, accountability, operational flexibility, budgetary, and acquisition risk issues associated with airpower PCS operations against mobile targets in a collateral damage sensitive environment. Conclusions and recommendations on the USAF's innovation strategy for addressing airpower PCS operations against mobile tactical targets will be presented in chapter 6.

Notes

1. "The practice of attacking selected targets with sufficient accuracy for high probability of kill and low collateral damage," as defined in John Birkler et al., *A Framework for Precision Conventional Strike in Post-Cold War Military Strategy* (Santa Monica, Calif.: RAND, 1996), iii.

2. Department of Defense, *Joint Statement on the Kosovo After Action Review*, 14 October 1999, n.p., on-line, Internet, 10 October 1999, available from http://www.defenselink.mil/news/Oct1999/b10141999_bt478-99.html.

Chapter 2

The Need for Precision Engagement against Mobile Targets

Of course we can only speculate, but I'll venture to say that without the accuracy of our current PGMs, we would have had a very difficult time controlling collateral damage in Kosovo. But without the ability to control collateral damage, we may not have been able to hold together a 19-member alliance. And without the alliance, the entire operation may have failed.

—Gen George T. Babbitt, USAF
Air Armament Summit 2000
15 March 2000

In the area of military innovation, Allan R. Millett states that there is a complex pattern of interaction between strategic assumptions, technology, operational doctrine, and civil-military interaction.¹ In regards to the R&D of precision-guided weapons, has the USAF performed a realistic assessment of these issues and their influence on precision engagement requirements and capabilities as Millett suggests? An analysis of the current strategic environment, political guidance, military operational doctrine, and recent airpower operations reveals this complex interaction and the need for better USAF PCS capabilities against mobile targets.

Strategic Environment

The United States has entered and will probably remain in a strategic environment that presents many opportunities and challenges. This strategic environment will create very dynamic and uncertain national security problems for the US military. The challenges will include—but are not limited to—regional, asymmetric, and transitional threats to US national interests.² US military forces will be involved in a variety of operations across the spectrum of war to include limited strikes, small-scale contingencies (SSC), major theater wars, and global conflicts. These operations will be characterized by dynamic changes in technology and increased coalition military operations. Political and social interests may demand that these military operations be executed with minimal collateral damage to friendly and enemy forces. Simultaneously, the US military has experienced a rapid reduction in its defense budget and a corresponding reduction in force structure. An analysis of world economics, geopolitical scenarios, threat trends, operational concepts, and trends in US military forces reveals an extremely complex set of challenges that the USAF may be called upon to address in the near future.³

Economic Scenario

The world economy has been likened to innovation cycles, which have accelerated over time. Currently, one theory holds that world economics is in the beginning of a Fifth Wave Digital Network Software New Media cycle that will continue to support information technology innovations.⁴ This innovation cycle will enable rapid exploitation of technology, adversarial technological surprise, and economic growth over the next 10 years. The exploitation of information technology will enable continued economic growth; however, US budgetary liabilities are projected to dramatically grow after 2010 due to increases in social security, medicare, medicaid, and other entitlement expenditures.⁵ Even in a strong economic environment, these expenditures will result in a US defense budget with a projected growth of approximately 1.5 percent annually through 2035.⁶ USAF appropriations of the Department of Defense (DOD) budget will most likely result in armament funding remaining static for the next 15 years. This static funding and air armament's small percentage of the Modernization Planning Program budget could result in future armament requirements exceeding appropriations and thus place the USAF in a position where it will be unable to fund needed armament R&D. Overall, armament R&D funding will continue to be a small USAF investment.⁷ In addition, world economic growth could be the catalyst that provides many countries with the resources needed to confront or challenge the US regionally.⁸ A regional competitor, taking advantage of technology advances, may take limited actions or achieve national objectives that directly conflict with US interests. In response to these economically based issues, US forces could be employed in a variety of military operations that may be heavily dependent on USAF armament capabilities.

Geopolitical Scenario

A strategic environment that is more complex and less predictable than ever before will result in a broad range of possible missions and military operations across the spectrum of war. The USAF will have to translate airpower capabilities to address military operations other than war (MOOTW), major theater war (MTW), and the possibility of global war (GW). In support of MOOTW—which includes humanitarian operations, peacekeeping, peace-making, and SSC operations—future airpower operations could be in response to or in support of ethnic-based counterinsurgencies, nonstate terrorism, peace enforcement, raids, limited attacks, limited strikes, and the neutralization of weapons of mass destruction.⁹ From 1990 to 1997, the US military responded to 45 SSCs, as compared to only 16 during the Cold War.¹⁰ It is likely this trend will continue, and the US military could be involved in six to seven “pop-up” SSCs a year. An MTW could involve a low-end regional competitor (LRC) or a high-end regional competitor (HRC). For example, an LRC could involve a Southwest Asian or North Korean adversary,

while an HRC could result from a threat from China. An HRC is not likely until after 2010.¹¹ Over the next 25 years, the United States could possibly be involved in conflicts with three LRCs and one HRC.¹² A global US competitor could arise after the year 2020 and increase the possibility of unlimited nuclear war within the next 25 years. In summary, the US military strength and strategy for the next 25 years must deter GW, be sized for MTW, and have the capabilities needed for MOOTW.¹³

Threat Trends

Threat trends will create great challenges for the USAF in air and space operations. The USAF's ability to provide this "freedom to attack and freedom from attack" will be challenged by advanced technology ground systems that will be transportable, relocatable, mobile, and very agile.¹⁴ These capable military systems could be employed in an asymmetric military strategy, which would make the destruction of these mobile targets very difficult. These military systems could incorporate decoys, Global Positioning System (GPS) jamming, or be strategically placed next to non-combatants in a high-risk collateral damage environment that could degrade or defeat USAF precision engagement capabilities. Camouflage, concealment, and deception efforts will make target detection and identification more difficult. In addition, the sale of technology and military systems will facilitate the worldwide proliferation of advanced technologies. This trend will result in the constant modernization of the threat. Technological parity with the United States may be obtainable by those adversaries who can afford it.¹⁵

US Military Operational Concept

Current US military operational concepts are based on a "new view of conflict" which provides responsive, executable courses of actions for political and military leaders.¹⁶ The "traditional view of conflict" was based on three phases: halt invading forces, build up military combat power while weakening the adversary, and then mount a decisive counterattack.¹⁷ This operational concept was based on an extended deployment and buildup period that provided the required military forces that would bring about the "culminating point" during counteroffensive operations. In the new view of conflict, the halt phase may be planned as the decisive point in a conflict and not just a buildup phase for US military forces.¹⁸ This military operational concept shifts the culminating point to the initial halt operations in an attempt to decrease the adversary's initiative and options while providing the United States and its allies additional options, branches, or sequels.¹⁹ These decisive halt operations will require military strategies and capabilities that maximize desired effects, minimize vulnerability, and may require the minimization of collateral damage. In this

new military operational concept, US airpower will be critical to halt operations and achieving the culminating point early in the conflict.

Trends in US Military Forces

US military forces are becoming lighter, leaner, and more lethal in support of current military operational concepts against a technologically advancing threat across the entire spectrum of war. Precision engagement capabilities will push submeter weapon accuracy. USAF armament R&D will focus on smaller weapons that provide a variety of carriage opportunities. Smaller weapons will allow for higher weapon loadouts per aircraft, meet internal carriage requirements, and uninhabited combat aerial vehicle (UCAV) carriage limits. Smaller weapons will also greatly reduce airlift requirements in support of Expeditionary Air Force operations. In response to collateral damage concerns and issues, airpower armament R&D will continue to focus on improving target identification and warhead effects capabilities. In addition, these smaller, lighter, leaner, and more lethal weapon systems will contribute significantly to US military sustainment capabilities.

Strategic Environment Conclusions

The strategic environment that the US military finds today and will find over the next two decades will be very dynamic and uncertain. Economic and technological growth over the next two decades will create opportunities and challenges for the US military. Military strength and strategies must deter GW, be sized for MTW, and have the capabilities needed for MOOTW. Threat trends will create great challenges for the USAF in air and space operations that support the US military's freedom to attack and freedom from attack. The military operational concept will be based on achieving the culminating point early in a conflict and providing a variety of responsive, executable courses of actions for political and military leaders. In addition, US military forces will become lighter, leaner, and more lethal in an effort to support military operational concepts against a technologically advancing threat across the entire spectrum of war. In response to this strategic environment, the USAF armament R&D strategy will be challenged by many of these issues as it attempts to improve the USAF's precision engagement capabilities.

National Security Strategy and National Political Guidance

The questions why, when, where, and how America will go to war in the current dynamic and uncertain strategic environment is founded in the na-

tion's national security strategy (NSS) and influenced by the guidance of its political leaders. US military engagement is based not only on threats to vital national interests but also on the political leadership's views, values, and beliefs. In addition, military action may at times be "event driven" and influenced by public opinion. US military action could take the form of a coalition or allied operations or it could be a single armed service in DOD that executes the military operation. Many of these issues that influence US military engagement can also affect USAF armament R&D.

Through the NSS, political leaders refine vital strategic interests and direct military engagement in support of these interests. The current 1999 NSS report to Congress, *A National Security Strategy for a New Century* (NSS), states that the three core objectives of the US NSS are to enhance America's security, to bolster America's economic prosperity, and to promote democracy abroad. A variety of vital, important, and humanitarian national interests support the achievement of these objectives. Central to achieving these objectives and responding to national interest will be US engagement and leadership in world affairs. This engagement and leadership will involve military forces, capabilities, and operations. The NSS further states, "To be secure we must not only have a strong military; we must also continue to lead in limiting the military threat to our country and the world."²⁰ The NSS stresses that US leadership and involvement in international crises and problems are essential to a prosperous America. However, political leaders, specifically the president, can define the criteria for US military action in response to real-world, real-time events. For example, in regards to ethnic cleansing in the Balkans, President William J. Clinton stated, "If the world community has the power to stop it, we ought to stop ethnic cleansing"²¹ and "If somebody comes after innocent civilians and tries to kill them en masse because of their race, their ethnic background, or their religion and it is within our power to stop it, we will stop it."²² Many of these interests and the resulting military actions may be driven by major media coverage, aroused political sympathy, or in support of US allies. This type of "political reality" in conjunction with traditional national interests will drive military operations across the spectrum of war in a highly dynamic strategic environment.

The US military may not have the capabilities and flexibility to respond to politically driven national interest operations. In regards to military involvement in US engagement and leadership abroad, the NSS states, "Transformation of our military forces is critical to meeting the military challenges of the next century. Exploiting the revolution in military affairs is fundamental if US forces are to retain their dominance in an uncertain world. Investment in R&D while closely monitoring trends in likely future threats are important elements of our transformation effort."²³ The NSS further states, "Transformation extends well beyond the acquisition of new military systems—we seek to leverage technological, doctrinal, operational, and organizational innovations to give US forces greater capabilities and flexibility."²⁴ However, the US military may not be prepared for

the current political dimension of war. Its doctrine and war-fighting capabilities may be focused on fighting large conventional adversaries, and it may be unable to address the political reality of asymmetric conflicts.²⁵ In addition, pop-up contingency operations may be reducing the US military's ability to transform its capabilities and benefit from a possible revolution in military affairs by pulling money from weapon R&D to pay for increased day-to-day operations.²⁶

The NSS is founded on continued US engagement and leadership abroad. In support of this engagement strategy, the United States will be required to respond to a full range of military operations across the spectrum of war in a dynamic strategic environment that will produce asymmetric threats and military strategies against the United States. Political aspects and realities will continue to challenge US military weapon research and modernization programs. The USAF's armament R&D must address these political realities as it transforms USAF precision engagement capabilities and flexibility to meet the military challenges of the next century.

Joint and USAF Doctrine

The significance of USAF precision engagement in military operations is reflected in joint and USAF doctrine. Joint doctrine clearly states the importance of precision engagement and its critical role in meeting political and public expectations for minimizing collateral damage. This precision engagement is directly linked to and supported by USAF doctrine. Due to the importance of USAF PCS capabilities in present and future military conflicts and in response to joint guidance, the USAF has made its core competency of precision engagement one of its top priorities.

Joint Doctrine

Joint Vision 2010 (JV 2010)—America's Military: Preparing for Tomorrow defines DOD's vision for the twenty-first century. It defines four operational concepts: precision engagement, dominant maneuver, focused logistics, and full-dimensional protection that will provide America the capability to "dominate an opponent across the range of military operations."²⁷ Former Chairman of the Joint Chiefs of Staff Gen John M. Shalikashvili stated, "*Joint Vision 2010* provides an operationally based template for the evolution of Armed Forces for a challenging and uncertain future."²⁸ *JV 2010*'s goal is to provide a conceptual template that guides and aids the armed services' doctrine, operations, acquisition, and training.

As one of the four operational concepts, precision engagement is emphasized throughout joint doctrine. *JV 2010* defines precision engagement as "a system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain the flexibility to reengage with precision when required."²⁹ The joint publication *Concept of Fu-*

ture *Joint Operations: Expanding Joint Vision 2010* calls for precision engagement capabilities from the armed services when it states, "Mindful of public concern and expectation to minimize the unnecessary risk or casualties, the National Command Authority will continue to seek quick, focused, effective, and decisive application of combat power when and where it is required."³⁰ It further states, "Long-range precision engagement will play an increasingly prominent role in power projection at all levels across the range of military operations."³¹ In today's strategic environment, an adversary's asymmetric military strategy will require this long-range precision engagement to have a capability against mobile threats in politically sensitive collateral damage environments. In response to this requirement and in support of *JV 2010*'s guidance, the USAF has evolved its doctrine to ensure air and space operations address emerging threats throughout the spectrum of war.

USAF Doctrine

In support of the US NSS, joint doctrine, and future military operations, the USAF has embraced precision engagement as one of its core competencies. USAF core competencies "provide insight into the specific capabilities that the US Air Force must bring to activities across the range of military operations."³² Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine*, states, "Air and space power is providing the 'scalpel' of joint service operations—the ability to forgo the brute force-on-force tactics of previous wars and apply discriminate force precisely where required."³³ It further defines precision engagement as "the ability to command, control, and employ forces to cause discriminate strategic, operational, or tactical effects."³⁴ Gen Ronald R. Fogleman, former Air Force chief of staff stated, "The essence of precision engagement is the ability to apply selective force against specific targets and achieve discrete and discriminant effects."³⁵ Former Secretary of the Air Force Sheila E. Widnall stated, "The Air Force of the 21st century must offer options for the employment of force in measured but effective doses."³⁶ She further states, "The Air Force core competency of precision engagement will remain a top priority in the 21st century."³⁷ USAF doctrine and comments by recent USAF leadership clearly demonstrate the importance of precision engagement in US military and airpower operations.

In accordance with and in support of joint and USAF doctrine, USAF precision engagement must provide the "scalpel" of joint service operations and the ability to apply selective force against mobile targets with discrete and discriminant effects. Today's strategic environment, national guidance, and world threats require airpower precision engagement capabilities that provide the freedom to attack mobile targets employed in an asymmetric military strategy in military operations throughout the spectrum of conflict with minimal collateral damage. In response to joint and USAF doctrine, the USAF's armament R&D must acquire weapon systems that, when called

upon, will provide the scalpel of US military operations against mobile as well as fixed targets. Recent USAF airpower operations in Deliberate Force and Allied Force emphasize this critical need for precision engagement while also revealing current USAF capabilities and limitations.

Recent USAF PCS Operations

Past USAF PCS operations have largely been associated with the destruction of fixed or stationary targets. However, recent military operations have shown a need for a PCS capability against mobile targets. Airpower operations during Desert Storm demonstrated the USAF's ability to attack and destroy fixed targets precisely and effectively with minimal collateral damage. It also demonstrated an ability to hit "dug-in" mobile targets in a desert environment. However, the apparent inability of airpower to locate and destroy Iraqi Scuds exposed limitations in USAF PCS capabilities against mobile targets. Recent airpower PCS operations in Deliberate Force (Bosnia) and Allied Force (Kosovo) have also revealed a need and possibly a deficiency in the USAF's ability to precisely attack mobile targets in urban or heavily wooded environments at standoff ranges with minimal collateral damage. The main cause of this deficiency was the difficulty in the identification and destruction of military targets in proximity to noncombatants and collateral damage sensitive areas.

Deliberate Force and Allied Force demonstrated the tremendous influence collateral damage sensitivity can have on military operations and the critical role precision engagement can play in successfully addressing this very challenging issue. In addition, both military operations reinforced the pivotal role of USAF airpower in the destruction of fielded force with minimal collateral damage in a complex political-military environment. However, these operations not only revealed current USAF PCS capability but also the limitations of current precision-guided weapon systems. The greatest limitation in USAF precision engagement operations was the ability to detect and identify fielded forces. This limitation greatly reduces airpower's inherent flexibility and adaptability in a complex political-military collateral sensitive operation. An analysis of Deliberate Force and Allied Force airpower operations highlights current USAF PCS capabilities and limitations and their effect on airpower-focused military operations.

Deliberate Force

Deliberate Force was a NATO military operation conducted between 30 August and 20 September 1995 to advance the cause of peace and stability in the Balkans region.³⁸ The strategic objectives of the campaign were the assurance of freedom of access to the cities in Bosnia-Herzegovina and the removal of heavy weapons from around Sarajevo.³⁹ These objectives were translated into the following military objective: "Take away what the Bosnian Serbs held dear and drive them to military parity with

the Bosnian Croats and Muslims."⁴⁰ Overall, the military priorities for Deliberate Force were force protection, minimizing collateral damage, and effective military strikes against Serbian targets.⁴¹ These objectives and military priorities resulted in a very restrictive airpower campaign that demanded an unprecedented reliance on USAF PCS capabilities.

Precision engagement enabled airpower to accomplish the strategic and military objectives of Deliberate Force. Deliberate Force was the first air campaign to predominately employ precision-guided munitions (PGM).⁴² Concerns over collateral damage led to this unprecedented use of PGMs. Airpower operations expended 1,026 bombs and missiles, of which 708 (69 percent) were PGMs.⁴³ Overall, the PGM to non-PGM ratio was a relatively high 2.3:1.⁴⁴ Of the 708 PGMs employed, 622 (87.8 percent) were expended by US aircraft.⁴⁵

USAF PCS capabilities were critical to airpower precision engagement operations. They contributed greatly to airpower's ability to target the Serbs' ability to wage war by attacking fielded forces with minimal collateral damage. The majority of PGMs employed in offensive air operations were laser-guided bombs (LGB). USAF aircraft did expend 23 air-to-ground missile (AGM)-65s (Maverick) and nine guided bomb unit (GBU)-15s, but more than 92 percent of the PGMs expended by USAF aircraft were LGBs.⁴⁶ LGBs are the USAF's primary PCS capability against mobile targets and fielded forces. Even though successful airpower precision engagement operations demonstrated the strength of current precision-guided weapon systems, the concerns over collateral damage and the targeting of fielded forces also exposed their limitations.

Concerns over collateral damage led to the unprecedented use of precision weapons in Deliberate Force. Collateral damage sensitivity was a political reality that drove the planning and execution of Deliberate Force airpower operations. NATO, United Nations (UN), and military leaders felt that if collateral damage incidents occurred, they could not have sustained the operation politically.⁴⁷ Due to this belief, collateral damage was a major issue in the target and weapon selection process. Its influence on weapon selection was illustrated during initial airpower operations when cluster bombs were the weapon of choice for eliminating mobile artillery systems. However, the combined forces air component commander prohibited their use due to the high risk of collateral damage.⁴⁸ Minimizing collateral damage was a self-imposed constraint that greatly influenced not only target selection but ROEs, weapon employment, and tactics.

Airpower ROEs during Deliberate Force were limited by USAF PCS capabilities. The concern over collateral damage resulted in many ad hoc operational ROEs. Some of these ROEs resulted in airpower operations in which (1) a target required positive visual identification before munition release, (2) aircraft could only expend one bomb at a time on a target, (3) air attacks were limited to certain times of the day, (4) aircraft were forced to increase the time between attacks conducted in the same target area or loiter over the target area due to smoke and debris effects on PGMs, and

(5) axes were restricted due to concerns of weapon malfunctions that could result in "long" or "short" weapons. Many of these restrictive ROEs were driven by current PGM limitations in target identification and terminal weapon effects. Limitations in current PGMs were also reflected in the tight control over airpower operations.

The desire to avoid collateral damage, together with the rapidly changing political situation, drove Gen Michael E. Ryan, commander of Allied Air Forces Southern Europe, to tightly manage the conduct and execution of the air campaign.⁴⁹ He believed that every bomb dropped had the potential to have a strategic effect on Deliberate Force operations.⁵⁰ To General Ryan, every bomb was a political bomb.⁵¹ The possibility of a "tactical event, namely the destruction of specific targets and the possibility of suffering casualties, potentially carried profound strategic implications" drove him to closely monitor the target selection process.⁵² This centralized control over airpower operations and target selection was an effort to prevent collateral damage and to fulfill General Ryan's desire to remain personally responsible for all associated decisions with the air campaign.⁵³ However, this tight control did have drawbacks. General Ryan's centralized control slowed the planning process, led to complaints about late target lists, and resulted in numerous last minute changes to the actual targets themselves.⁵⁴ Few knew the reasons for these changes and delays, and many aircrew "felt that they were at the end of a whip."⁵⁵

The tight control over air operations in Deliberate Force resulted in the Combined Air Operations Center's (CAOC) apparent involvement in air tactics.⁵⁶ Aircrews recognized the importance of minimizing collateral damage but felt that the CAOC's involvement in tactics, to include the number of passes over a target and the setting of weapon-release pulses, in conjunction with a low tolerance for misses and mistakes took "the judgment out of the cockpit."⁵⁷ At one point in the campaign, aircrews were required to perform a dry pass over the target prior to releasing a weapon. This ROE was quickly rescinded when the aircrew voiced concerns over increased risk, but it clearly demonstrated the aircrew frustration with the CAOC's involvement with tactics. In addition, the requirement to visually identify (VID) a target prior to weapon release drove aircrews to perform low-altitude passes over the target area. Aircrews were allowed to VID targets with aircraft sensors, but sensor limitations and adverse weather limited this capability. Target identification requirements associated with collateral damage concerns and limitations in airpower target identification capabilities in regard to precision engagement operations drove many of the ROEs, which resulted in the removal of tactical judgment from the cockpit. Improving the target identification capabilities of PGMs could put tactical judgment back in the cockpit.

Even with the associated drawbacks, in the context of the political environment and with the available airpower precision engagement capabilities, General Ryan's close control over airpower operations was critical in the success of Deliberate Force. However, this tight control and personal

involvement in airpower operations greatly reduced the inherent flexibility and adaptability of airpower operations. This tight operational control was not only due to collateral damage concerns but in part to limitations in USAF precision engagement capabilities. In a larger and longer duration campaign involving numerous sorties and targets, it would not have been possible or effective to execute such tight control over airpower operations. Therefore, if centralized control is not a feasible option in minimizing collateral damage during airpower operations, airpower PCS capabilities must be improved to meet the same collateral damage requirement.

Another aspect to the issue of airpower precision engagement operations in Deliberate Force was the possibility that the Bosnian Serbs did not effectively employ an asymmetric strategy that effectively exploited NATO collateral damage concerns. Had they strategically placed military forces more effectively and more extensively in close proximity of non-combatant and collateral damage sensitive areas, airpower precision engagement operations may not have been as successful. Additionally, had they taken military action that would have forced NATO airpower to engage and destroy more ground forces in order to meet strategic and military objectives, airpower precision engagement operations would have been more difficult and would have probably resulted in more collateral damage incidents. The fact that "Bosnian Serb leaders made no effort to exploit collateral damage politically indicates that they had little to exploit" will not be lost on future adversaries.⁵⁸ The belief that "Had NATO and UN leaders expected enough collateral damage to give the Serbs a political lever, they probably would not have approved the initiation of Deliberate Force, or if such damage had begun, they probably could not have sustained the operations politically for long" will be exploited by future US adversaries.⁵⁹ It was apparent the lessons of Deliberate Force were not lost on the Serbs in their next military confrontation with NATO.

Allied Force

Allied Force operations further validated airpower's pivotal role in complex collateral damage sensitive political-military operations. Airpower precision engagement capabilities limited collateral damage while accomplishing evolving strategic and military objectives. Airpower once again proved its flexibility in a campaign characterized by evolving objectives. As in Deliberate Force, USAF PCS capabilities played a critical role in precision engagement operations. However, Slobodan Milosevic's asymmetric strategy, which exploited NATO sensitivity to collateral damage, further exposed limitations in USAF PCS capabilities initially identified in Deliberate Force airpower operations.

Allied Force was a 78-day NATO political-military operation from March to June 1999 to bring an end to Serbian atrocities in Kosovo.⁶⁰ The operation's primary interests were ensuring the stability of Eastern Europe, thwarting ethnic cleansing, and ensuring NATO credibility.⁶¹ The strategic objectives of

the operation were to (1) demonstrate NATO's opposition to Serbian aggression in the Balkans, (2) deter Milosevic from continuing and escalating his attacks on civilians and reverse his ethnic cleansing, and (3) damage Serbia's capacity to wage war against Kosovo and degrade its ability to wage military operations.⁶² The strategy to achieve these objectives focused on airpower operations against strategic targets throughout the Federal Republic of Yugoslavia (FRY) and Serbian-fielded forces in Kosovo.

Airpower operations were critical to the success of Allied Force. Airpower precision engagement was a cornerstone of military operations. Its impact on Serbian military operations in FRY, through attacks on fixed infrastructure targets and fielded forces, created a political-military environment that caused Milosevic to yield to NATO's objectives and demands.⁶³ USAF PCS capabilities increased the probability of kill against a given target, minimized collateral damage, and minimized aircraft attrition. The USAF's latest generation PGM, the JDAM, was employed in substantial numbers for the first time and provided many of these capabilities and effects. However, JDAM employment was limited to fixed targets and by target coordinate requirements. Even though a substantial number of JDAMs were used, the majority of PGMs employed during Allied Force were LGBs.⁶⁴ LGBs were also the PGM of choice against mobile targets.

Airpower operations in Allied Force were undoubtedly the most precise and resulted in the lowest collateral damage in military history. However, there were shortfalls, challenges, and limitations associated with precision engagement operations against mobile targets. Serbian-fielded forces were a key strategic focus of the air war as a result of NATO's objectives to minimize ethnic cleansing and reduce Serbian military strength.⁶⁵ Airpower was successful in reducing Serbia's military strength through the destruction of fielded forces; but the identification and destruction of mobile targets, with minimal collateral damage, created challenges for airpower throughout Allied Force. In its report to Congress on Operation Allied Force, DOD stated, "While it is clear that our weapon systems were highly accurate and highly effective, it is apparent that we need to improve our capability to conduct precision engagement, especially against mobile targets that are easy to hide."⁶⁶ In addition to concealment efforts, the weather and the Serbs' asymmetric strategy to exploit NATO's collateral damage concerns also had a tremendous effect on the identification and destruction of mobile targets.

The extensive use of LGBs and adverse weather conditions during Allied Force operations limited airpower precision engagement capabilities against mobile targets. Airpower was required to operate under weather conditions that had 50 percent cloud coverage more than 70 percent of the time.⁶⁷ The successful employment of an LGB requires the aircrew to first detect and identify the target with an onboard sensor and then provide weapon guidance via a laser designation on the targets, unless there is a ground designation capability. Both of these tasks require an unobstructed line of sight (LOS) with the target for an extended period of time, and this ability is greatly

degraded by adverse weather conditions. GPS-guided weapons, like JDAM, do provide an all-weather capability; but target coordinate requirements greatly limit their use and effectiveness against mobile targets. In addition, air-dispersed combined effects munitions (CEM) submunitions were an effective weapon when properly targeted and employed; however, the risk of collateral damage prevented their widespread use against mobile targets. CEM submunitions expended in Kosovo contributed greatly to collateral damage, and their effects are still being addressed militarily and politically today.⁶⁸ Therefore, adverse weather conditions during Allied Force in conjunction with PGM limitations greatly hampered airpower's ability to detect, identify, and destroy mobile targets.

Allied Force was not a traditional military conflict. Military operations were not characterized by the direct clash of massed military forces but by an airpower precision engagement operation against infrastructure targets and fielded forces in an effort to achieve strategic and military objectives. These airpower operations were executed in a complex political-military environment, against a ruthless adversary, and in less-than-ideal environmental conditions.⁶⁹ It could be contended that as a result of Deliberate Force airpower operations, Milosevic chose to fight NATO with an asymmetric military strategy that included the use of terror tactics against civilians, the exploitation of the premium NATO placed on minimizing civilian casualties and collateral damage, the creation of refugee movements that resulted in a humanitarian crisis, and the conduct of misinformation campaigns.⁷⁰ This asymmetric approach was an attempt to exploit political concerns about target selection, collateral damage issues, and military operations against enemy forces that were intentionally intermingled with civilian refugees.⁷¹ This asymmetric strategy was not only empowered by NATO's collateral damage concern but also by limitations in airpower's precision engagement capabilities against mobile targets.

Many of these limitations were illustrated on 14 April 1999 when a USAF F-16 attempting to attack fielded forces with LGBs mistakenly attacked a convoy of civilian personnel, which resulted in the death of over 70 civilians.⁷² Operating at medium altitude due to air defense threats, onboard sensor and weapon limitations inhibited the correct identification of the targeted vehicles, which facilitated the collateral damage. This collateral damage incident greatly affected air-to-ground operations and greatly influenced airpower's ability to attack fielded forces.

Airpower precision engagement operations demonstrated the tremendous flexibility, adaptability, and collateral damage reduction capabilities along with the limitations of current USAF MITL-guided weapon systems. An example was an attack on a target located in an urban environment. The aircrew visually identified the target as a church and promptly guided the MITL-guided weapon into an open field, thus minimizing collateral damage. Three other collateral damage minimizing maneuvers were performed when the aircrews determined that the prebriefed target description did not match the target displayed in the cockpit weapon video.⁷³

These events demonstrate the ability of MITL-guided weapons to prevent or reduce collateral damage through aircrew detection and identification of incorrect target coordinates or targeting process errors. Once released from the aircraft, current autonomous weapons have no capability to detect, reduce, or minimize any targeting or intelligence errors. The limitations of current USAF MITL weapon systems were also demonstrated when an AGM-130 impacted a railroad bridge just as a train was crossing the bridge. Due to the AGM-130's limited seeker field of view and seeker performance, the aircrew did not detect the train in time to redirect the weapon. A wider seeker field of view and improved overall seeker performance may have enabled the aircrew to detect the train earlier and thus provide an opportunity to redirect the weapon.

Airpower operations in Allied Force were successful in achieving political and military objectives. However, more importantly, the limitations associated with airpower precision engagement operations during Allied Force have resulted in numerous lessons learned, recommendations, and observations. These recommendations and observations include but are not limited to the following:

- While airpower precision engagement weapon systems were highly accurate and effective against fixed targets, there is a need to improve airpower precision engagement capabilities against mobile targets and to address potential GPS jamming vulnerability.
- Weapon R&D efforts need to continue to assess the "development of weapons that fill gaps and shortfalls in current capabilities and their subsequent certification on launch platforms."
- R&D efforts also need to continue to "assess technologies that will ensure flexibility and enable all-weather precision strikes, including on-board and off-board accurate targeting capability against fixed and mobile targets, that can be executed within minutes of target assignment."
- "Assess future weapon inventories to achieve the right balance of capabilities for future requirements."
- R&D effort must develop better sensors and communications to improve precision engagement capabilities to target an adversary's mobile-fielded forces.⁷⁴

Many of these recommendations and observations specifically address current USAF precision engagement shortfalls in the detection, identification, and destruction of mobile targets. Allied Force further demonstrated how these shortfalls and limitations—along with collateral damage concerns—could be exploited by an adversary's asymmetric military strategy. To counter this asymmetric threat, the USAF's armament R&D strategy must address improvements to USAF PCS capabilities against mobile targets.

Deliberate Force and Allied Force demonstrate the characteristics of likely future military and airpower conflicts. Future airpower operations

will cover the full spectrum of war, including MOOTW. Airpower operations will be conducted in complex political-military environments with evolving strategic and military objectives. Political concerns will drive airpower operations and result in tactical events having strategic implications. Limiting collateral damage is a political need that will influence airpower operations. PGMs will be the airpower weapon of choice in future conflicts to adhere to political limitations while achieving strategic and military objectives.

Conclusions

This analysis of the current strategic environment, political guidance, military operational doctrine, and recent airpower operations reveals the complex interaction and influence these factors have on USAF armament R&D and the critical need for PCS capabilities against mobile targets. The strategic environment the United States finds today and will find over the next two decades will create challenges for the USAF armament R&D strategy. USAF armament funding will remain static and continue to represent a small percentage of future DOD and USAF budgets. Future airpower operations will cover the full spectrum of war, including MOOTW. The USAF's ability to provide freedom to attack and freedom from attack will be challenged by advanced technology ground systems that will be transportable, relocatable, mobile, and very agile. US military operations will be based on achieving the culminating point early in a conflict and providing a variety of responsive executable courses of action for its political and military leaders. In addition, US military forces are becoming lighter, leaner, and more lethal in an effort to support its military operational concepts against a technologically advancing threat across the entire spectrum of war. Political aspects and realities will continue to influence US military weapon modernization programs. In light of and in response to these issues and stated joint and USAF doctrine, the USAF's armament R&D strategy must acquire weapon systems that when called upon will provide the capability to apply selective force against mobile targets with discrete and discriminant effects.

Recent military operations are evidence of the importance and the steadily improving effectiveness of airpower to achieve national, political, and military objectives. Airpower precision engagement capabilities, specifically USAF capabilities, are the main reason for this importance and effectiveness. Minimizing collateral damage is becoming a rule of modern warfare; therefore, airpower strategies, operations, and weapons R&D must treat this issue honestly and explicitly.⁷⁵ Today, airpower's inherent versatility, flexibility, and responsiveness are linked in large part to its precision engagement capabilities. Any reduction or failure to improve precision engagement capabilities will reduce these inherent airpower abilities and strengths.

Col Phillip S. Meilinger summarized the importance of precision engagement of future airpower operations when he stated,

Because precision is possible, it will be expected. Air warfare has thus become highly politicized. Air commanders must be extremely careful to minimize civilian casualties and collateral damage. All bombs are becoming political bombs, and air commanders must be aware of this emerging constraint—hundreds of millions of people worldwide will judge [via CNN] the appropriateness of everything an air commander does. This reality must be factored into the decision process, because in the future airmen may be required to wage war bloodlessly and delicately.⁷⁶

Today's strategic environment, current US political guidance, joint and USAF doctrine, and recent airpower operations clearly demonstrate a critical need for PCS capabilities against mobile targets. Even though recent airpower operations have revealed limitations in current USAF PCS capabilities, a more in-depth analysis of current USAF target identification and guided weapon systems is required before addressing the USAF's armament R&D strategy for the next decade.

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Chapter 3

USAF Target Identification and Guided Weapon Systems Capabilities

Wars may be fought with weapons, but they are won by men.

—Gen George S. Patton Jr.

The union of global attack and precision strike capabilities enables the USAF to “apply discriminate force precisely where required.”¹ This capability to attack targets with exactness, intensity, minimal collateral damage, and a relative economy of force is provided by a vast inventory of sensor and guided weapon systems. These operational systems incorporate a variety of sensor, guidance, and warhead technologies to provide the required accuracy in target identification, weapon guidance, and terminal effects. An analysis of these sensor and weapon systems and their enabling technologies reveals the USAF’s present guided air-to-ground PCS capabilities and limitations against mobile targets. These current capabilities and limitations will greatly affect airpower’s ability to achieve future political objectives in a manner that is appropriate to the strategic environment.

USAF Sensor Systems

Presently, the USAF has four airborne sensor systems that can provide real-time or near-real-time target information in the surveillance, detection, tracking, and identification of mobile ground targets. These sensor systems include the U-2, E-8C joint surveillance, target attack radar system (JSTARS), RC-135 Rivet Joint, and the UAV Predator aircraft. The U-2 is a high-altitude reconnaissance aircraft that can provide real-time and near-real-time multisensor photo, electro-optical (EO), infrared (IR), and radar imagery of mobile ground targets. The Advanced Synthetic Aperture Radar System (ASARS)-2, employed by the U-2, is a combined synthetic aperture radar (SAR) and moving target indicator (MTI) surveillance radar that provides real-time, high-resolution ground maps. The ASARS-2 has an MTI spot mode which detects slow and fast moving targets and quantifies an individual target’s type on an SAR imagery background, a stationary target search mode which provides a large target discrimination capability, and a stationary spot mode which provides enhanced detail and discrimination against smaller targets.² The E-8C JSTARS aircraft is a battle surveillance platform that employs its onboard AN/APY-3 system to detect and track mobile ground forces. The AN/APY-3 is a side-looking airborne radar (SLAR) that incorporates SAR and MTI capabilities. Its

MTI/wide area surveillance (WAS) capability detects, locates, and classifies slow-moving vehicles. The MTI technique that is used allows differentiation between wheeled and tracked vehicles. The MTI/sector search mode provides enhanced image resolution and attack guidance. Other operating modes may include an enhanced SAR for "super" resolution imagery and an inverse SAR for target recognition.³ The RC-135 Rivet Joint is an electronic intelligence collecting reconnaissance aircraft that has the ability to detect, locate, and identify emitting mobile targets with its automatic emitter location system.⁴ The Predator, the USAF's newest UAV, provides real-time mobile target information by either an onboard EO, IR, or Tactical Endurance Synthetic Aperture Radar (TESAR) sensor system. The TESAR system is an SAR-based system that can generate a fully focused, near-real-time strip map imagery. With P-coded GPS data, the map can provide target location with a 25-meter circular error probability (CEP).

These systems provide effective, all-weather, WAS and tracking; however, they are limited in their real-time ability to classify and identify ground mobile targets. Recent military operations demonstrated limitations in their dynamic targeting, geolocation accuracy, and timeliness.⁵ The real-time information that these systems provide is directed to the surface-based command facilities or used to cue other weapon systems to a target area. These systems have limited ability to automatically initiate and maintain a track on specific vehicles or vehicle groups, provide automatic cues to areas of important activity, or sort vehicle type in a high collateral threat environment. Because these systems have limited automated capabilities in target tracking and target identification in conjunction with no weapon assignment or weapon terminal guidance capability, the weapon system tasked to destroy a mobile target must still identify the target and provide terminal weapon guidance. Until these sensor systems are tied to a networked guided weapon system, these systems can only provide target cueing or target recognition capabilities that still require target identification by other weapon or sensor systems. Until there is a netted fire control system that can provide a precision tracking capability against mobile targets, identification and weapon guidance must reside within the same weapon system. Because of this requirement, many USAF guided weapons combine the sensor and shooter capability into one weapon system.

USAF Guided Weapon Systems

Many military and government officials incorrectly group all guided weapons together into one category. There are, in fact, two main categories of guided munitions and two accuracy classifications. Guided munitions fall into the following categories: MITL or autonomous weapons.⁶ MITL weapons are those weapon systems that have the capability to guide a munition to a specific target with a "man/operator" providing the ter-

minimal guidance to a desired mean point of impact (DMPI). Current MITL weapons are reliant on either laser designation or data-link control for weapon guidance. Based on the weapon's terminal guidance, MITL systems can be further broken down into two subcategories: laser MITL guidance or data-link MITL guidance. Autonomous weapons are those weapons that require minimal or no operator inputs after release from the delivery platform. An onboard seeker or external guidance system (e.g., GPS) provides terminal guidance. There are no clear lines of distinction between the three categories. Some guided weapons retain both MITL and autonomous capabilities. However, all guided weapons have a primary or preferred terminal guidance. Therefore, the categorization of guided weapons used in this study is based on a weapon's primary terminal guidance. Guided munitions are also typically classified into two accuracy classifications. If a weapon has a CEP of 13 meters or less, it is called an "accurate" weapon. If it has a CEP of three meters or less, it is called a "precise" weapon.⁷

Laser MITL-Guidance Weapons

Laser MITL guidance is defined as the ability of a man/operator to provide terminal guidance of an air-to-ground LGB to a specific DMPI through the use of a ground or air laser designation. LGBs incorporate a terminal seeker and guidance kit that responds and guides to reflected laser energy. The kit consists of a guidance control unit (GCU) attached to the front and a fixed set of fins on the rear of the weapon. The laser target designator's reflected coded laser energy is "seen" by the GCU seeker. GCU inputs to the control fins keep the reflected laser energy centered in the seeker's field of view and the bomb "flies" to the designating laser spot on the target. These kits can be placed on many types of general purpose bombs, turning a "dumb" bomb into a "smart" bomb. The majority of guided weapons in the USAF's weapon inventory are LGBs and include GBU-10/12/24/27/28/36 munitions.

Strengths of LGBs include accuracy (precision), real-time target intelligence, cost (\$10,000–\$125,000), multi-aircraft capability (A-10, F-16, F-15E, B-52, F-117), penetration capability (hard-target-kill), mobile target capabilities, limited target battle damage assessment (BDA), and quantity (more than 50,000). Precision accuracy and real-time target intelligence are the greatest strengths of laser MITL-guidance weapons in the destruction of mobile targets. These characteristics provide the USAF a high degree of accuracy while reducing collateral damage risk in air-to-ground operations. These weapons give the aircrew the ability to observe the target area during prelaunch, postlaunch, and—most importantly—during the weapon's terminal phase of flight, thus providing precision and collateral damage minimizing characteristics.

Weaknesses of LGBs include onboard or off-board laser designation requirements, LOS between target and designation platform, limited stand-

off range, target identification requirements, and poor adverse weather/environment (e.g., rain, fog, dusk and/or smoke) performance. In the destruction of mobile targets, the most critical weaknesses are the lack of adverse weather capability, limited standoff ranges, and target identification. The successful employment of an LGB requires weather conditions that allow the detection, recognition, and identification of the target; stability of the laser designator on the target until weapon impact; and reception of the reflected laser energy by the seeker. Adverse weather conditions that negatively affect any of these requirements greatly reduce LGB capabilities against mobile targets. Smoke and dust can also have a similar effect on laser designation operations. In addition, atmospheric effects and the fact that LGBs are gravity bombs with no propulsion capabilities after release greatly limit their standoff ranges. LGBs require the laser designating and weapon carrying aircraft to fly in close proximity of the target, two to four nautical miles (NM); thus they are classified as direct attack weapons. Employment altitude is a factor that influences the weapon's range. Typically the greater the employment altitude, the greater the range. Some LGBs can be "tossed" from low altitude, but even these ranges are limited. Target identification abilities are based on the capabilities and limitations of the target sensor and laser designation system. The primary system used by the USAF to acquire, track, identify, and laser designate ground targets is the low-altitude navigation and targeting infrared for night (LANTIRN).

The LANTIRN is a two-pod mounted system that includes the AN/AAQ-13 navigation pod and the AN/AAQ-14 targeting pod. The targeting pod is the primary sensor system and contains a stabilized wide and narrow field forward-looking infrared (FLIR) and a laser designator/range finder. The IR sensor uses temperature differences of the target environment to generate a black and white representation of the target area on a video display in the cockpit. The amount of area that can be "viewed" by the sensor is limited by the FLIR's field of view (FOV) and field of regard (FOR). The FOV of a seeker is the actual area that can be viewed through the sensor. The FOR is the range that the sensor's FOV can be slewed (e.g., 30 degrees up, down, left, and right). The FLIR has an FOV of 1.7 degrees by 1.7 degrees in narrow and six degrees by six degrees in wide and an FOR of ± 150 degrees.⁸ FOV and FOR limitations can create challenges for the weapon operator in the detection, recognition, and identification of mobile targets. Many operators have equated the searching for mobile targets with the LANTIRN systems to that of "viewing the world through a soda straw."

The target detection, recognition, and identification capabilities of the LANTIRN system are greatly affected by aircraft speed, altitude, range from the target, atmospheric conditions, and the target characteristics. Many of these factors are a function of the threat environment and weapon employment requirements. The aircraft's speed influences the time the aircrew has to resolve the scene displayed in the cockpit if the aircraft is performing a single pass over the target area. Aircraft speed has

little or no effect on target identification if the aircraft is in a holding flight profile over the target area. However, loitering over the target area is not possible in a high threat environment. Dwell time on a target decreases as aircraft speed increases. There is an inverse relationship between distance from the target and dwell time in regards to target identification. Dwell time decreases the lower or closer the sensor is with respect to the target. A lower altitude may provide higher target scene fidelity, but the time the aircrew has to analyze the scene may not be enough for target identification. In general, target identification capability decreases as the distance (range or altitude) from the target increases due to atmospheric conditions and sensor limitations. Therefore, a threat environment that forces less than optimal sensor or weapon employment altitudes or ranges can negatively affect the identification and destruction capabilities of LGBs against mobile ground targets. However, even when employed in optimal conditions, the LANTIRN system has marginal mobile target identification capabilities.

The USAF plans to add GPS guidance kits to its inventory of LGB weapons to overcome adverse weather limitations and give the munitions an autonomous all-weather guidance capability.⁹ This modification will greatly improve LGB adverse weather capabilities, but it will also include the limitations of GPS guidance. These limitations include the reduction in accuracy from precision to accurate capabilities, increased target coordinate fidelity requirements, and GPS guidance countermeasures. These limitations greatly reduce LGB effectiveness against mobile targets. However, the addition of GPS guidance will increase the overall flexibility and versatility of LGB weapons. Even with present limitations, LGBs are one of the most versatile PCS weapons.

Data-link MITL-Guidance Weapons

Data-link MITL-guidance weapons evolved out of the requirement for precision guidance in high threat environments. Data-link MITL weapons provide precision accuracy at standoff ranges. These weapons incorporate a seeker and data-link control system that enable aircrew-input commands throughout the weapon's flight profile. This category of weapons includes the GBU-15, AGM-130, and AGM-142 HAVENAP. The strengths of these MITL weapons include precision accuracy, standoff range, penetration capability, target identification, and limited target BDA. Weaknesses include data-link vulnerability, LOS requirements between weapon and control platform, cost, limited inventory, limited aircraft carriage and employment (F-15E and B-52), and a limited adverse weather employment capability. With the recent addition of GPS guidance to many MITL PGMs, the adverse weather limitation is no longer a factor. If the target is never seen by the aircrew or is obscured by bad visibility, the weapon will impact with GPS accuracy. However, if the aircrew is able to identify the target prior to impact, last second updates to weapon guidance can be made

to achieve precision accuracy. GPS-aided guidance can also minimize human errors associated with MITL systems.

The greatest strength of data-link MITL weapons is the real-time flexibility it brings to air-to-ground operations. This flexibility is based on the aircrew's ability to access real-time target information through the weapon seeker, analyze this information, and input targeting guidance as required until target impact. The addition of GPS guidance further improves data-link MITL weapons' overall flexibility by giving it an autonomous-guidance option. A GPS-aided data-link MITL guided weapon system is the most capable and flexible air-to-ground guided weapon system in the USAF.

Because of their capability and flexibility, data-link MITL munitions lend themselves to employment in politically sensitive operations where collateral damage must be limited. Data-link MITL PGMs provide surgical destruction with the maximum flexibility. The weapon seeker greatly improves target identification during the last phase of the weapon's flight profile. With a human in the guidance system loop, the weapon can be monitored throughout its flight profile; and targeting changes can be made until weapon impact. If intelligence data is incorrect, these capabilities provide a "last chance" check that may catch errors and prevent the inadvertent destruction of a politically sensitive target. If required, the weapon can be flown into the ground and thus provide a "called back" capability.

Today's USAF data-link MITL-guidance weapons lack many significant features that would greatly improve their effectiveness. Present MITL-guidance weapons have limited FOV and FOR, which greatly limits target detection capabilities. Greater FOVs and FORs are required when targeting mobile targets. The incorporation of GPS midcourse guidance into MITL-guidance weapons has aided fixed target detection but only marginally improves mobile target detection. Present data-link MITL systems only allow the operator one look at the target. The addition of loiter and "go-around" capabilities would allow multiple target area overflies and thus increase the chances of target identification and destruction.¹⁰ With current IR and EO sensor capabilities and weapon speeds in excess of 600 feet per second, the operator typically only has five to 10 seconds to identify the target prior to impact. Against mobile targets, this identification time is reduced to only three to five seconds. Target misidentification greatly increases the risk of collateral damage and the "wasting" of a limited asset. A weapon system that enables the operator to command the weapon to perform a reattack flight profile anywhere in the attack profile could greatly improve target identification and greatly reduce collateral damage in the destruction of mobile targets. In addition, this capability could be coupled with a cockpit "playback" feature, which would allow the operator to review previous attack profiles and target scenes—thus further improving target identification capabilities. An analysis of the USAF's data-link MITL-guidance precision weapons reveals the absence of these capabilities.

The USAF's inventory of MITL-guidance weapon systems includes the GBU-15, AGM-130, AGM-142, and AGM-65. The GBU-15 is a modular unpowered glide weapon that incorporates an EO or imaging infrared (IIR) guidance seeker, a guidance module, and a data-link system on an MK-84 general purpose bomb to provide a limited standoff MITL precision-guidance weapon. The combination of the weapon's limited seeker performance, limited seeker FOV and FOR, and unpowered glide flight profile with no go-around capability greatly limits its mobile target detection and identification abilities. The weapon has a limited standoff release range of five to 10 NM; however, the weapon can be controlled well beyond these ranges. Recent modifications include the addition of GPS guidance to aid in target detection and provide a limited adverse weather capability. The GBU-15 is a single-carriage weapon only employed by the F-15E. It has a unit cost of \$300,000 and is the most numerous data-link MITL-guidance weapon in the USAF inventory (more than 2,000).

The AGM-130 is a component weapon based on the GBU-15 that integrates an EO or IIR seeker, inertial navigation system (INS), data-link system, and a rocket motor onto an MK-84 munition. Recently the weapon has been modified with GPS guidance capability to provide midcourse guidance and a limited adverse weather capability. Like the GBU-15, the weapon has no go-around capability and its seeker has a limited FOV and FOR. The weapon system has a unit cost of \$422,000, and USAF's inventory of AGM-130s is limited. The limited inventory is complicated by the fact that there is no production capability until 2004 due to the relocation of the AGM-130 production facility.¹¹ Due to the unit cost and limited inventory factors, the AGM-130 may not be the "financially proportional" weapon of choice against mobile targets. The AGM-130 is a single-carriage weapon only employed by the F-15E. Recent development test programs investigated the integration of a "lightweight" 1,000-pound version for the F-16, but at present there are no plans to incorporate the AGM-130 on the F-16.

Similar to the AGM-130, the AGM-142 HAVENAP incorporates an EO/IIR seeker, inertial navigation unit (INU), data-link control system, and a propulsion system to create a precision guidance standoff capability. The AGM-142 has a unit cost of \$670,000 and—like the AGM-130—the USAF has a limited number of these weapons. Unsuccessful employment of the AGM-142 during Allied Force operations identified failures in the weapon flight control system. However, according to the USAF, these failures have been corrected.¹² The weapon system is a single carriage weapon employed only by the B-52.

The AGM-65 Maverick is a precision-guided air-to-surface missile that is primarily employed in a launch-and-leave operation but has some MITL capabilities. Prior to launch, the missile's EO or IIR seeker is used to detect and identify ground targets. Once a target is located, the weapon seeker is "locked on" to the target and the weapon is released. The missile guides to the designated target as long as the seeker remains locked on. The AGM-65 has no data-link capability, and therefore no guidance updates can be made after

the missile is launched. The AGM-65E version has a laser MITL-guidance capability. The AGM-65's 10 to 12 NM range is dependent on the weapon sensor performance. Target detection and identification is also seeker dependent. The AGM-65 does have a real-time mobile target targeting capability that can minimize collateral damage; but due to the requirement to identify the target prior to launch and its limited range, its PCS capability against mobile targets is limited in a high threat environment.

The flexibility and real-time targeting provided by current data-link MITL-guidance weapon systems gives the USAF a limited but needed PCS ability against mobile targets in high-risk collateral damage environments. Even though these weapon systems have a target identification capability, their flight profile and seeker limitations greatly reduce their overall effectiveness. In addition, some of these weapons have limited employment standoff ranges, which may require an aircraft to penetrate enemy air defenses even though the data-link control can be in excess of 200 NM. Also, all data-link MITL weapon systems require specialized aircraft and specialized aircrew training, which could limit their employment opportunities. In addition, their relatively high cost and limited numbers greatly hinder their use against mobile targets except in extreme circumstances.

Autonomous-Guidance Weapons

Autonomous-guidance weapons are launch-and-leave munitions that require no operator input after release from the aircraft. Once the weapon is released from the delivery platform, the weapon guides itself to the target through an onboard guidance system that receives guidance updates or target information from an onboard or off-board guidance system or sensor. All guidance information to the weapon is automated. Many next generation weapons fall into this category. The majority of weapons in this guided weapon category have an INU guidance system that receives position updates via the GPS, which provides guidance to the target. This category of guided weapon includes GBU-31/32 JDAM, wind corrected munition dispenser (WCMD), AGM-154 joint standoff weapon (JSOW), and the AGM-86C CALCM. The majority of autonomous weapons are classified as accurate weapons. These weapons are only as accurate as the GPS information and the target coordinates provided to the weapon. The strengths of autonomous guided munitions include accuracy, multi-aircraft carriage, all-weather, standoff, and in some cases affordability (e.g., JDAM at approximately \$20,000 per unit).¹³ Weaknesses include limited GPS precision guidance, limited numbers, intelligence requirements, GPS vulnerability, cost, limited mobile target capability, and a limited target identification capability.

The JDAM is a low-cost, GPS-aided, inertial guidance kit that when attached to unguided MK-83, MK-84, and BLU-109 munitions provides an autonomous, all-weather, and highly accurate guided weapon. Prior to release, the JDAM receives updated target coordinates from the aircraft's avionics

systems. The JDAM is capable of in-flight retargeting prior to release. Once released the inertial guidance kit guides the weapon, with periodic GPS updates to the INS, to the last updated target coordinate passed to the weapon prior to launch. After release, no target coordinate updates can be passed to the JDAM. The JDAM has 13-meter CEP with GPS guidance and 30-meter CEP with INS-only guidance. Precision accuracy, three-meter CEP, has been obtained during testing with differential GPS guidance. Its maximum stand-off range of 15 NM is dependent on employment parameters. Presently, the JDAM is employed on B-2 and B-1 aircraft. The JDAM is a capable, all-weather, accurate guided weapon; but its lack of terminal seeker guidance and its target coordinate requirement limit its effectiveness against mobile targets. There are product improvement programs (PIP) for JDAM that may incorporate an SAR seeker. The addition of an SAR terminal seeker could increase accuracy by mitigating target location error and GPS errors for fixed targets but would not provide an autonomous target identification capability against mobile targets. The main focus of JDAM PIPs is to provide counter-measure capabilities to negate GPS jamming effects.

The GPS-Aided Targeting System is a unique, autonomous, guided weapon capability that incorporates the B-2 and JDAM. Based on the B-2's SAR map of the target area, the JDAM GPS target coordinates can be updated prior to release. This SAR map-based update reduces the difference between the target's actual location and its GPS location. This difference, known as GPS bias, can cause errors in excess of 10 meters if not corrected.

The WCMD is a tail guidance kit that was developed to overcome high-altitude release wind dispersion. It can be fitted to cluster bomb unit (CBU)-87/89/97 dispenser weapons. Target coordinates are passed to the weapon from the aircraft prior to launch. Once released from the aircraft, the guidance system—which consists of an INS guidance unit and movable tail fins—corrects for wind drift transients after launch. The WCMD has no GPS-guidance capability, and its accuracy against mobile targets is primarily dependent on the submunitions in the dispenser. The intent of WCMD is to enable tactical munition dispensers (TMD) to correct for the effects of launch transients, ballistic errors, and unknown winds during the weapon's flight profile to the dispenser's functioning point.¹⁴ The guidance system has an accuracy of 85 feet and is employed at direct attack ranges.¹⁵

The JSOW is a winged glide bomb dispenser with a GPS/INS guidance system that can be launched at standoff ranges in excess of 40 NM.¹⁶ The weapon flies to a predetermined point over a target area and dispenses either BLU-97 CEM or BLU-108 sensor fused weapons (SFW). Like the WCMD the weapon has GPS-accurate guidance capabilities, while target detection and precision capabilities are dependent on the submunition being dispensed. Currently a version with an IIR terminal sensor and data link for precision attack of strategic point targets is under development.¹⁷ Presently the AGM-154 is employed on the F-16 aircraft.

The most advanced submunition in the USAF inventory is the SFW. The SFW is an unpowered wide area cluster munition that provides day, night,

and adverse weather capability against mobile armor targets. It contains 10 BLU-108 submunitions with four skeet projectiles per submunition. The skeet smart warhead uses a side-mounted IR sensor that performs a conical search scan as the submunition falls to the ground. Target detection is based on IR emissions from combustion engines; and the weapon has very limited target identification capabilities, which inhibits its use in high-risk collateral damage environments. A preplanned product improvement (P3I) may incorporate a dual-mode seeker with an active laser and two-color passive IR detector to provide better target detection capabilities, but the weapon will still have limited target identification capabilities.

The AGM-86C CALCM is a long-range, inertial navigation GPS-aided guided cruise missile with a conventional blast fragmentation warhead. It has a range of 1,100 kilometers and 15-meter CEP.¹⁸ The weapon was designed to provide long-range accurate attacks against strategic fixed targets.¹⁹ The weapon is employed only by the B-52.

Present USAF autonomous-guidance weapon systems provide a day, night, all-weather PCS capability at relatively low cost and in numbers that do not limit PCS operations. However, these capabilities are only against fixed targets and at limited standoff ranges. GPS autonomous-guided weapon systems have no real-time kill capability against mobile targets. Many autonomous GPS-guided weapons are due to receive PIPs that incorporate accuracy improvement initiatives. These improvements hope to improve both clock and ephemeris errors and atmospheric errors in conjunction with plans to modify receiver software to utilize 12 channels instead of only five, which should reduce target location errors (TLE).²⁰ These improvements may reduce TLE but provide minimal increases in mobile target capabilities and do not address larger target location uncertainties or provide target identification capabilities.

TLE is the difference between the desired aim point and the actual target location at the time a sensor imaged the target.²¹ Target location uncertainty (TLU) is the difference between the predicted target location and the actual target location at the time of weapon arrival due to target movement. TLU is only associated with mobile targets, while TLE is associated with both fixed and mobile targets. The effectiveness of today's GPS autonomous-guided weapons is greatly limited by the lack of target identification and the inability to overcome TLU.

Conclusions

The USAF has a vast array of guided air-to-ground weapons, which enable very effective and efficient PCS operations against fixed ground targets. However, in execution of one of the most difficult tasks in air-to-ground operations, the destruction of small very mobile targets in adverse weather with a strong air defense in a high-risk collateral damage environment, these weapons provide only limited capabilities.²² Presently,

LGBs, the GBU-15, the AGM-130, and the AGM-65 MITL weapon systems provide the greatest PCS capabilities; however, these systems have significant limitations. Airborne designated LGBs have adverse weather and standoff limitations, while the LANTIRN system has only a marginal target identification capability which is greatly dependent on employment tactics. The GBU-15 has limited all-weather and standoff capabilities; but even with precision guidance, its large warhead could cause considerable collateral damage. Its lack of loiter and go-around flight profiles greatly limits its target identification capabilities. Except for greater standoff ranges, the AGM-130 and AGM-142 have the same limitations as the GBU-15. The AGM-65 has a much smaller warhead than the GBU-15, AGM-130, and AGM-142; but it has a limited standoff range and no target identification or update capability after release.

The greatest shortfall in GPS autonomous-guided weapons is their inability to meet target identification requirements and location uncertainties associated with mobile targets. TLE and TLU will continue to limit GPS-guided autonomous weapon effectiveness. Seeker advances may ultimately overcome these limitations, but current seeker technologies have only demonstrated the ability to identify large strategic fixed targets. A few seeker technologies have demonstrated an identification capability against stationary mobile targets, but these technologies will not be operational within the next 10 years. Presently no USAF operational air-to-ground weapon system has autonomous target acquisition capabilities against mobile targets.

The greatest challenges in the employment of guided weapons against mobile targets are target location, target identification, and terminal weapon guidance. In response to these known shortfalls, the USAF's weapon R&D strategy is focused on autonomous-guidance weapon systems. Every new air-to-ground weapon research or development program related to the destruction of mobile targets is pursuing an autonomous-guidance capability. No new air-to-ground weapon research or development program addressing this shortfall has MITL-guidance capabilities, even though MITL-guided weapons provide the best target identification capabilities available today and most likely for the next 10 years. An analysis of near-term and future weapon systems and associated technology reveals that this focus on autonomous-guidance weapon systems and rejection of MITL-guidance weapon systems may result in the inability of the USAF to perform PCS operations against mobile targets in a high-risk collateral damage environment during the next decade.

Notes

1. Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine*, 1 September 1997, 30.
2. Martin Streetly, *Jane's Airborne Electronic Mission Systems* (Alexandria, Va.: Jane's Information Group, 1998).
3. Ibid.

4. Ibid.
5. Department of Defense, *Report to Congress, Kosovo/Operation Allied Force After-Action Report* (Washington, D.C.: Government Printing Office, 31 January 2000), 56.
6. John Birkler et al., "A Framework for Precision Conventional Strike in Post-Cold War Military Strategy," RAND Report (Santa Monica, Calif.: RAND, 1996). This report has six guided air-to-ground guided weapon categories: man-in-the-loop laser-guided terminal sensor (GBU-10/12/16/24/27/28, Maverick, GBU-15, AGM-130, and AGM-142); GPS-aided INS alone (CALCM, JDAM, JSOW, and WCMD); TERCOM or GPS-aided INS plus scene-matching sensor (TLAM-C BLK II and BLK III); GPS-aided INS plus target-imaging sensor (TLAM-C BLK IV, JDAM PIP, JSOW P3I, and JASSM); antiemitters (HARM); and smart submunitions (SFW). Due to this analysis focus on man-in-the-loop and autonomous weapon systems, the five different autonomous weapon categories are viewed as a single guided weapon category with variations in capabilities.
7. "Precision Munitions: Today's Capability, Tomorrow's Promise," briefing slides (Langley AFB, Va.: Directorate of Requirements, Headquarters Air Combat Command [ACC], 1998).
8. Chris Johnson, *Jane's Avionics* (Alexandria, Va.: Jane's Information Group, 1998), 247.
9. Bryan Bender, "USAF Looks to Phase Out LGBs," *Jane's Defense Weekly*, 17 November 1999, 45.
10. Itzhak Gat, "Precision Strike-Technological Trends," *Military Technology*, vol. 23, issue 5 (1999): 31.
11. Will Hargrove, Boeing Corporation, interviewed by author, 14 December 1999.
12. David Martin, "The Weapon That Didn't Work," *60 Minutes*, news program, 11 January 2000, n.p., on-line, Internet, 16 January 2000, available from <http://www.cbs.com/now/story/0,1597,147988-311,00.shtml>.
13. David A. Fulghum, "Isolated, Serb Army Faces Aerial Barrage," *Aviation Week and Space Technology*, 19 April 1999, 28.
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15. "Precision Munitions."
16. "MAP."
17. Lennox.
18. Ibid.
19. *Report to Congress*, 92.
20. "MAP."
21. Lt Col Will Haas and Maj Ben Quintana, "Miniaturized Munition Capability," briefing slides (Langley AFB, Va.: Headquarters ACC, 20 January 2000).
22. Birkler et al., 24, 30.

Chapter 4

Future Weapon Systems Capabilities

Without air munitions there is no air power.

—Gen George T. Babbitt

Precision strike—the capability to attack targets with the exactness and intensity required to achieve the desired military effect with minimum collateral damage—requires accuracy in target detection, recognition, identification, weapon guidance, and warhead terminal effects.¹ An analysis of present USAF PCS capabilities against mobile targets in a high-risk collateral damage environment reveals a shortfall in meeting many of these requirements. Many of today's precision weapons have accuracy in weapon guidance but lack accuracy in target detection, recognition, identification, and warhead terminal effects when employed against mobile targets. Many of these shortfalls are due to weapon sensor and guidance limitations against mobile targets. To overcome these limitations, the USAF's R&D strategy is turning to weapon systems that leverage current and future technologies to create an autonomous precision weapon capability against mobile targets.

Kill Chain Elements

Many variables and requirements must be addressed to effectively destroy mobile targets in a high-risk collateral environment. These requirements include very accurate location of the target (absolute or relative), precise location of DMPI, susceptibility of the target to functional kill, and high-resolution imagery of the target and objects in the vicinity of the target that allow for positive target identification. Variables include collateral damage tolerances, weather, enemy countermeasures, and level of intelligence.²

The successful operational task of detecting, identifying, tracking, and delivering munitions with high accuracy against mobile targets requires many successive steps. The first task that must be accomplished is a wide area search and detection of the target to cue the attack. Then target acquisition capabilities must provide accurate identification and location so a weapon can be guided to the target. Flyout, midcourse guidance, and target updates must be provided to the weapon en route to the target to aid target identification and terminal guidance. During the critical terminal phase of flight, guidance of the weapon is performed either by the continuation of en route or midcourse guidance or by a terminal seeker guidance capability. Finally, observations of the weapon effects need to be

obtained for BDA.³ These tasks, in conjunction with other requirements, make up the kill chain elements (fig. 1).⁴

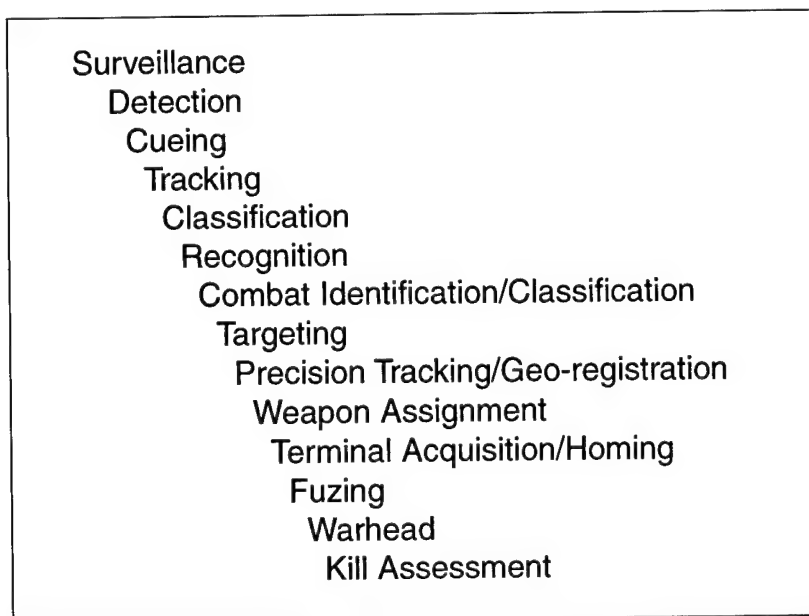


Figure 1. Kill Chain Elements

The terms *detection*, *classification*, *recognition*, *identification*, and *characterization* are defined as follows:

Detection. The level at which targets can be distinguished from non-targets to include trees, rocks, or image processing artifacts.

Classification. The level at which target classes can be resolved (i.e., building, vehicle, or aircraft).

Recognition. The level at which target subclasses can be determined (i.e., a tracked vehicle, wheeled vehicle, tank, or armored personnel carrier).

Identification. The level at which the model/make of the target can be resolved (i.e., an M60, M1, or T72 tank).

Characterization. The level at which detailed physical characteristics of a target can be determined (i.e., MiG-29 with air-to-air missiles).

The USAF and other DOD agencies are pursuing two research, development, and operational approaches in an attempt to create autonomous weapon systems that perform many of these tasks. One approach focuses on networking a "system of systems" to create detection, identification, tracking, and precision control tracking solutions that can be transmitted to a variety of guided munitions.⁵ This approach exploits recent advances in sensor, communications, guidance, and processing technologies. The other approach focuses on the integration of terminal seeker and guidance technologies that when combined, provide an automatic target recognition (ATR) or automatic target acquisition (ATA) precision-

guided weapon. The air-to-ground weapon employed in the first approach relies on off-board sensor and guidance data, while in the second approach the weapon relies on onboard seeker and guidance capabilities. An analysis of imaging, guidance, and munition systems related to each of these approaches reveals many of their strengths and weaknesses. Because target identification is the first and most challenging requirement in both approaches, an analysis of current and near-term imaging technologies will be performed first. A basic understanding of current and near-term imagery technology is required before these two R&D strategies can be fully analyzed.

Imaging Technologies

Many seeker technologies are being developed to overcome the challenge in identifying and attacking mobile targets. These seeker technologies include but are not limited to EO (ultraviolet [UV], visible, and IR), radio frequency (RF), SAR, millimeter wave, laser radar, and multispectral seeker technologies. No single imagery technology provides the optimal capabilities against mobile targets in all situations and environments. Depending on the target characteristics and target environment, each seeker technology has certain strengths and weaknesses. IR technology seekers provide high-resolution images but have limited performance in adverse weather conditions. RF technology seekers provide all-weather capabilities but have less inherent lateral resolution. Active millimeter wave (MMW) technology seekers provide high-resolution images but suffer from high attenuation in heavy moisture. Passive millimeter seekers have no active scanning or radiation requirements, but their performance is driven by properties of the target and background scene. A multispectral technology seeker which incorporates two or more seeker capabilities would be very effective over a wide range of targets, backgrounds, and weather conditions but would increase the seeker size and cost.

Passive IR Seeker Technology

Passive IR is the most mature seeker technology and offers high-resolution and identification capabilities against mobile targets at relatively low cost. The seeker uses an array of IR detectors scanned across the target area and creates an image from the emitted thermal radiation. Typically the seeker operates in either the three-to-five micron or eight-to-12 micron wavelength bands. Temperature differentials between objects in the scanned area enable a processor to search for the target feature preloaded into the seeker's memory. Because the seeker is a passive system, it cannot detect targets obscured by foliage, fog, thick haze, dust, or smoke. In addition, due to the numerous variables that affect thermal images, autonomous IR seekers must account for a variety of possible variances in target identification and classification. These variables include

time of year, time of day, cloud cover, solar loading, and target and background materials.

Synthetic Aperture Radar

SAR is an active radar sensor system that achieves higher resolution than could theoretically be acquired by the actual physical antenna. The higher resolution is achieved by using forward motion of the sensor platform and phase shifts between transmitted pulses to create a larger antenna length than the actual platform antenna. This longer antenna length provides a high-resolution capability. SAR technology provides a two-dimensional all-weather imaging system that provides a limited target identification capability.

SAR technology has been incorporated in both sensor and seeker systems. SAR sensor and seeker systems have demonstrated target identification capabilities against large fixed targets to include buildings, bridges, and other cultural objects. SAR sensor systems have demonstrated an identification capability against mobile targets; however, SAR seekers have not shown this capability.⁶ A SAR sensor has demonstrated one-foot resolution, while SAR seekers have been limited to 10-foot resolution.

Another limitation associated with SAR is the required flight profile to acquire SAR imagery. To achieve accurate resolution, the seeker system must move cross-range to the target. This forces the seeker platform to initially fly an angled-off attack azimuth to the target, then turn directly towards the target and rely on inertial navigation or monopulse radar for terminal guidance. This flight profile requirement could degrade SAR seeker accuracy against mobile targets. GPS guidance could improve terminal guidance accuracy, but any GPS jamming could reduce guidance accuracy. Many low-cost INU drift rates require GPS lock to be maintained throughout the terminal phase to achieve precision accuracy. SAR is a mature sensor technology presently employed on the F-15E, B-2, and E-8C JSTAR radar systems; but it has limitations when incorporated into a weapon seeker that prevents it from being used to identify and destroy mobile targets.

Millimeter Wave

MMW seeker technology addresses some of the limitations of passive IR. The MMW frequency band, 30 to 300 GHz, offers many atmospheric transmission windows that have better atmospheric moisture penetrating capabilities. Even though MMW seekers are susceptible to high attenuation in heavy rains, they are still considered to have an all-weather capability. Most MMW seekers are active systems, where the seeker transmits radiation and then measures the reflected radiation from objects in the target area. With proper beam modulation, the reflected radiation from each scanned object in the target environment is processed to enable range measurements. The range information is used to create a one-meter

resolution image of the target area being scanned by the seeker. Drawbacks to active MMW seekers include degraded imaging capabilities in target environments with background clutter. Background clutter in the target area creates high noise levels, which decrease seeker contrast sensitivity and range resolution. The active MMW is also susceptible to radar countermeasures.

Laser Radar

Laser radar (LADAR) is an active sensor system that operates in the IR spectrum. The seeker scans a modulated IR laser beam across the target area and processes the reflected laser radiation to obtain range measurements to objects in the target area. These range measurements, less than one foot in range resolution and six to 12 inches in spatial resolution, are processed by the seeker to create a detailed three-dimensional (3-D) image of the target area. Because the seeker is transmitting an IR beam and measuring the reflected radiation, its imaging capabilities are not dependent on target area emitted thermal radiation; thus it does not have the target imaging challenges associated with passive IR systems. LADAR's targeting imaging capabilities are not dependent on seasonal, time of day, or other temperature-related environmental factors. However, because LADAR does operate in the IR spectrum, the seeker technology does suffer attenuation problems of the radiated IR laser beam. Heavy-moisture atmospheric conditions could attenuate the transmitted and reflected signal strength to a level that prevents the target area from being imaged. LADAR technology seekers have demonstrated mobile target identification capabilities and have been called "the most promising" seeker identification and precision guidance technology.⁷

Complementary LADAR/MMW Seeker (CLAMS)

Because there are strengths and limitations associated with each imaging technology, there are research efforts to combine two or more imaging technologies. Even though advances in solid-state LADAR and associated 3-D autonomous target acquisition algorithms coupled with GPS/INS midcourse guidance systems are providing smart weapon capabilities, there are countermeasures and limitations associated with each imaging system. To overcome these countermeasures and limitations, an imaging system operating in a different portion of the frequency spectrum can be combined with the LADAR system. The CLAMS program focuses on the integration of an MMW imager with a LADAR imager. An MMW offers adverse weather and poor visibility conditions capabilities in addition to a wide field of view cueing for the LADAR. A passive MMW system also provides a degree of covertness for the guided weapon system. In addition, a second MMW imager offers a backup capability to the weapon system if the LADAR system fails or malfunctions. One of the objectives of the

CLAMS program is to determine the feasibility and affordability of a munition-sized combined MMW and LADAR seeker.⁸

Summary of Imaging Technologies

No one imaging technology provides optimal performance in all situations. Each technology has strengths and weaknesses that exploit different phenomenologies that aid in the detection, identification, and destruction of mobile targets. RF imaging systems are not as sensitive to atmospheric conditions as IR systems but have less inherent lateral resolution. Passive systems provide a covert capability but are greatly affected by emissivity and temperature differences between the target and target background scene that can cause numerous variances in a target image. A general summary of advantages and disadvantages associated with imaging technologies is shown in table 1.⁹

Table 1
Imaging Technologies

	Short Wavelength (UV/Visible/IR)	Long Wavelength (MMW, RF)
Active Systems	<ul style="list-style-type: none"> + High Lateral Resolution + Measure Range (Target Shape) + Low Cost - Sensitive to Atmospheric Conditions 	<ul style="list-style-type: none"> + Adverse Weather Capability + Measure Range (Target Shape) - Poor Lateral Resolution - Historical Perception of High Cost
Passive Systems	<ul style="list-style-type: none"> + High Lateral Resolution + Covert + Measure Physics of Scenes + Potential Low Cost - Sensitive to Atmospheric Conditions 	<ul style="list-style-type: none"> + Adverse Weather Capability + Covert + Measure Physics of Scenes - Imaging Passive MMW Is an Emerging Technology

Automatic Target Recognition versus Autonomous Target Acquisition

Many of these imaging technologies are being developed to enhance sensor and seeker capabilities to provide USAF air-to-ground flexibility, target detection/identification, precision guidance, and increased weapon lethality. In addition, it is hoped these imaging technologies will provide an ATR or ATA PCS operations capability that could increase standoff

ranges, increase weapon effectiveness, and eliminate or reduce MITL guidance requirements.

Automatic Target Recognition

ATR is the ability to reliably and automatically recognize sensed visual, IR, and radar images or electronic signatures that provide a significant operational benefit to the target detection, target identification, intelligence analysis, or BDA.¹⁰ Present ATR technology does not provide sufficient accuracy or reliability to perform autonomous lethal attack against mobile targets, but it does provide an ability to rapidly screen target areas and cue weapon systems. ATR technology has the ability to provide additional target information from target areas of interest to target identification estimates, which could aid MITL weapon systems.

This "aiding" of MITL systems is typically provided by a cascading process, which includes detection/bulk filtering, false alarm discrimination, classification/indexing, and recognition stages.¹¹ Detection and bulk filtering rapidly reduce regions of interest by eliminating target areas that do not exhibit target-like properties or characteristics from the search area. False alarm discrimination then further refines regions of interest by removing target areas that with a more detailed and context-dependent set of features do not exhibit target-like characteristics. The next step, classification and indexing, associates regions of interests with more likely target characteristics. The final step, recognition, identifies specific types of objects within a given classification.

These cascading steps are achieved with a variety of classification/recognition algorithms that match attributes of imagined target area objects with a priori information about potential or desired targets. However, the greater portion of ATR algorithm R&D has focused on statistical pattern recognition and template matching. Statistical pattern recognition partitions the space of possible target identities according to how target signature attributes can be partitioned, while template matching codifies the topological structure of the target signatures for all possible unknowns from an a priori database and matches this against the unknown signature to select its most likely identity.¹² These algorithms provide ATR capabilities but require tremendous target signature attribute databases to handle variances related and caused by target environmental and atmospheric variations. A model-based target characterization algorithm overcomes these variance effects.

Model-based algorithms codify the a priori information about unknown targets using an explicit model of the desired target geometry coupled with a sensor model that transforms the target geometry into signature attributes.¹³ This ATR algorithm technique enables signature prediction to be directly tailored on-line to the specific condition under which the unknown target signature is observed and thus is adaptable to real-time data that may not have been collected previously. This model-based algo-

rithm requires fidelity of the target geometry and sensor models to predict the expected target signature attributes, and today's higher fidelity and faster sensor models are providing these capabilities.¹⁴

In USAF air-to-ground related mission areas, ATR technology and capabilities improve target detection/identification accuracy and speed and reduce aircrew workload. However, ATR technology has had only limited success in the autonomous detection, identification, and destruction of mobile targets. The integration of ATR into PCS operations against mobile targets has been focused on aiding the MITL guidance target analyst and has not provided a true autonomous PCS capability against mobile targets. This capability may be provided by an autonomous target acquisition system.

Autonomous Target Acquisition

The primary difference between ATR and ATA is the confidence in target classification and system performance. While ATR strives to improve the target classification accuracy and speed of an MITL system, ATA strives for autonomous target detection, identification, characterization, and aim point selection by the weapon system. A high confidence in performance will be required from an ATA-based weapon system before it will be accepted and employed operationally. ATA systems perform similar cascading steps as ATR systems and also employ a model-based target characterization algorithm.

ATA not only provides an autonomous target identification capability but also provides the precision guidance capability required to place the munition's warhead on the most vulnerable part of the target.¹⁵ This precise placement of the warhead increases the munition's effectiveness, which decreases required aircraft sorties, which in turn could decrease aircraft attrition. Furthermore, an ATA guidance capability reduces the size of the warhead needed, thus reducing the overall size of the weapon, which could increase aircraft weapon loadouts.¹⁶

Both ATR and ATA capabilities are being supported by the two major fundamental technology thrusts in USAF conventional armament R&D: advanced guidance and ordnance. The advanced guidance thrust researches and develops terminal seekers and guidance and navigation technology that provides precision guidance, while the ordnance thrust researches and develops explosives, warheads, fuses, weapon airframe controls, and weapon release equipment.¹⁷ However, while ATR and ATA capabilities support many USAF mission areas, for PCS operations against mobile targets ATA is the most critical capability and considered the highest risk factor in future air-to-ground precision-guided weapons.

System of Systems Approach

The system of systems approach (SSA) networks and fuses information and capabilities from a variety of systems to provide a PCS capability

against mobile targets.¹⁸ This approach combines sensor, communication, processing, guidance, and precision weapon technologies to create an affordable highly automated netted sensor fire-control weapon system solution. The SSA addresses present technology and PCS operation limitations, which require weapon systems with sophisticated sensors, MITL guidance, or wide area dispersion munitions in the destruction of mobile targets. The SSA collects sensor data from a variety of off-board sensor systems for the purpose of surveillance, target identification, geolocation, and target tracking and passes this information in real time to guided weapons to provide a precision capability against mobile targets. One of the SSA goals is to provide an affordable precision capability to destroy mobile targets while minimizing collateral damage.

Presently no SSA real-time capability against mobile targets exists. Many technology programs have demonstrated or are addressing SSA requirements, but these systems are only in the R&D phase and will not result in an operational capability within the next 15 years.¹⁹ These R&D programs address improvements in the surveillance, detection, tracking, identification, and precision weapon engagement capabilities against mobile targets. The majority of these programs are technical risk reduction laboratory efforts that hope to facilitate the rapid transition and development of follow-on operationally capable systems.

The detection and identification of mobile targets is one of the major challenges facing sensor exploitation and operations. An additional issue is how best to exploit sensor data in the destruction of mobile targets.²⁰ The goal of many sensor programs is to provide a robust capability to engage all surface targets by collecting sensor data from a variety of sources for a variety of tasks. Providing these capabilities requires sensors to deal with numerous countermeasures including partial obscuration, articulation of turrets, intraclass variations, and radar absorbing materials. Programs attempting to provide mobile target identification in this challenging environment include moving target exploitation (MTE), moving and stationary target acquisition and recognition (MSTAR), affordable moving target engagement (AMSTE), and Discovery II.

Moving Target Exploitation

The MTE program attempts to combine airborne high-resolution MTI and moving target SAR imagery to detect, track, and identify time-critical mobile targets. While MTI can provide WAS, it is limited in its ability to separate and identify target vehicles from other vehicles in the search area. High-resolution SAR can perform this target identification requirement and overcome this MTI limitation. Combining the two systems could provide a WAS and target identification capability. The goal of the MTE program is to provide the operational commander an all-weather, day/night ability to detect, identify, and track high-value moving ground targets.²¹

Moving and Stationary Target Acquisition and Recognition

In the area of automatic target recognition, the MSTAR model-based approach has demonstrated promising results. The MSTAR program focuses on the development, integration, and evaluation of advanced automatic target recognition capabilities against tactical and strategic targets using SAR imagery. The objective of the program is to design, construct, and demonstrate an accurate and robust ATR system capable of recognizing time-critical targets through the use of air-to-ground two-dimensional SAR imagery. MSTAR is a laboratory-based program that is attempting to provide ATR algorithms and processing tools for future imagery technologies. The ATR algorithm models targets, backgrounds, and target/background interactions and calculates the uncertainty with which they can be measured, extracted, and predicted to account for obscuration, clutter layout, camouflage, diffuse scattering, multipath reflection, and other operational phonologies that negatively affect the identification of mobile targets. The program hopes to overcome the larger target, sensor, and background combination requirements of ATR systems that rely solely on precomputed templates, which require large amounts of target data.²²

Affordable Moving Target Engagement

The AMSTE program goes beyond the MTE program and focuses on weapon system technologies that enable precision, affordable, all-weather engagement of moving targets. The goal of the program is to develop, investigate, and evaluate technologies leading to affordable architectures for the destruction of mobile targets. The fundamental concept of the program is using networked sensors to provide precise, high revisit rate detection of mobile targets to produce a precision fire-control solution that could be provided as a command guidance signal to precision-guided weapons. The program uses a network of air-based and space-based ground moving target indicating (GMTI) radar and SAR systems to provide a precision guidance solution on a mobile target. The guidance solution is then used to provide in-flight real-time target updates to a variety of precision-guided weapon systems.

One of the main objectives of the program is the destruction of the correct mobile target with no collateral damage. To achieve this objective, the program does not anticipate the requirement to develop new sensors, weapons, or communication technologies and hopes to leverage current technologies to keep the solution affordable. The Defense Advanced Research Projects Agency conducted a feasibility study in 1998 in the areas of GMTI radars, precision fire-control tracking, and command guidance portions of the program. The study concluded the AMSTE concept was technically feasible, with the precision fire-control tracking solution having the highest technical risk. However, an operational system based on AMSTE will be available, at the earliest, in 2015.²³

Discovery II

Discovery II is a technology demonstration program to develop an affordable space-based integrated GMTI and SAR imagery system. The program is pursuing "acceptable risk" technologies that will provide a space-based, low-cost multimode GMTI/SAR system; an advanced command, control, communications, computers, intelligence, surveillance, and reconnaissance capability complementing UAV and aircraft architectures providing near continuous mobile target detection, tracking, and targeting; and a direct data-link precision engagement capability to the war fighter. An operational space-based radar system with these elements will not be available within the next 20 years.²⁴

The SSA is exploiting advances in technology to overcome present sensor shortfalls and provide an affordable mobile target engagement capability. New GMTI sensors will provide better resolution and more accuracy. Emerging GMTI systems will provide vast amounts of usable GMTI data. SAR systems will enable target identification in high-risk collateral damage environments. Guided weapons will provide the ability to precisely target DMPs. Advances in communications will provide the ability to network dispersed sensors and shooters. A networked system will provide off-board accurate hand-over attack solutions against mobile targets. All of these operations will be accelerated by the explosive growth of computer processing power to a real-time mobile target engagement capability. Even with this exploitation of technology and computer processing power, none of these SSA programs will provide an operational capability until well beyond 2015. Therefore, in the near term, a guided weapon system with onboard target identification and precision guidance provides the most promising PCS capability against mobile targets.

Autonomous-Guided Weapon Approach

Precision weapon capabilities are directly related to the precision requirements and challenges of the era during which they were developed. Recently acquired or near-term precision-guided weapons, including JDAM, JSOW, WCMD, and SFW were developed under requirements that included accuracy, adverse weather capability, increased standoff range, autonomous guidance, multiple kills per pass/multiple targets per release sequence, multi-aircraft carriage, improved hardened target capability, and affordability.²⁵ These requirements were based on the need to (1) hold all high-value, highly defended targets at risk from the start of hostilities, (2) blunt enemy armored spearheads and saturate target complexes, and (3) penetrate heavily fortified targets and destroy the capacity for mass destruction.²⁶ Many of the USAF's recently acquired guided weapons have these characteristics and capabilities. The destruction of mobile targets while minimizing collateral damage was not a driving factor in the acquisition of many of these weapons. Today's PGM requirements and challenges are slightly different and include accu-

racy, standoff, wide spectrum of targets, aircrew workload, autonomy, real-time-in-cockpit targeting, countermeasures, and reduced collateral damage. The new challenges of mobile, highly defended targets in close proximity of noncombatants are driving today's precision weapon research, development, and acquisition strategy.

The USAF's long-term air-to-ground weapon acquisition strategy will reduce the number of weapon systems from over 20 to no more than two to three programs per mission area. In the area of direct attack and close air support (CAS), USAF air-to-ground capabilities will be limited to three or four weapon systems. Present capabilities, which include a mix of old generation weapons (CBU-89, AGM-130, AGM-142, GBU-15, Maverick, and LGBs) and first generation autonomous weapons (WCMD, JSOW, JDAM, and SFW), will be replaced by second generation systems such as joint air-to-surface stand-off missile, miniaturized munition, and a next generation CAS weapon.²⁷ These weapon systems will be developed based on a variety of mission need statements (MNS) and JAOA studies. In the area of the destruction of stationary and mobile targets, Combat Air Force Mission Need Statement (CAF MNS)-304-97 states the critical need for a miniaturized munition capability (MMC). This MMC MNS and its related Acquisition Decision Memorandum calls for a weapon system with the following capabilities: increased sortie effectiveness (more kills per pass); minimization of collateral damage; adverse weather effectiveness; increased aircraft munition loadout (internal and external); small logistics footprint; low mission cost; and the ability to hit fixed, relocatable, and mobile targets.

In support of this MMC MNS, the USAF and USN are conducting a JAOA to evaluate a wide variety of USAF, USN, and DOD contractor weapon systems concepts. The goal of the JAOA is to determine the best weapon system concept that will increase the combat capability of all US DOD aircraft with an affordable cost and acceptable technology risk level. The analysis includes the identification of low to moderate risk alternatives; identification of key operational requirements document performance parameters; and the evaluation of logistics support, total life cycle cost, and concept of operations considerations.

The JAOA was scheduled for completion in September 2000, but preliminary analysis indicated two categories of munitions will be required to meet the MMC MNS fixed and mobile target requirements. A fixed target miniature munition (FTMM) is a near-term capability, but a mobile target miniature munition (MTMM) will not be feasible in the near term, even with directed accelerated funding. These conclusions were based on the ability of the FTMM to leverage current JDAM technology, while an MTMM would require R&D to acquire a new weapon system. In response to the preliminary findings, the USAF has requested Office of the Secretary of Defense and congressional approval to start the acquisition of a 500-pound JDAM weapon system.²⁸

This MK-82 JDAM acceleration decision by the USAF chief of staff and the secretary of defense is an interim capability solution to limiting col-

lateral damage when attacking fixed strategic targets. However, this GPS guidance-based weapon system will only provide limited capabilities against mobile targets. In response to this continued shortfall, numerous miniaturized technologies and weapon systems are being researched and developed. With hopes of meeting this critical mobile target need, USAF armament laboratories have focused their efforts on next generation seeker technologies that may provide the target detection and classification, precision guidance accuracy, smaller warheads, and overall smaller munitions capabilities needed to meet MMC MNS requirements.

The effort to meet MMC requirements has resulted in two fundamental technology areas or thrusts for conventional armament: advanced guidance and ordnance.²⁹ The advanced guidance thrust is focused on the development of terminal seekers, as well as guidance and navigation technology that will provide the precision needed against fixed and mobile targets.³⁰ This thrust includes acquiring autonomous, all-weather, countermeasures-resistant, precision seekers for air-to-ground weapons and real-time targeting updating capabilities to the weapon on the location of mobile targets—as well as the ability to change to an alternate high-value target. The laboratories are working to develop terminal seekers, sensors, processing, guidance, and navigation technologies that could result in an affordable all-weather precision guidance autonomous weapon capability against mobile targets.³¹ One of the goals of the laboratories is to develop a seeker that provides target identification and classification, highly accurate guidance, and the ability to provide enough information to determine warhead operations that maximize weapon lethality.³² The USAF and civilian laboratory efforts have resulted in LADAR, SAR, MMW, and IR seekers that have demonstrated varying success in the detection and identification of mobile targets in adverse weather, clutter, and countermeasure environments. These seekers have been integrated into a variety of autonomous miniaturized munition (AMM) weapon concepts.

These AMMs represent the second generation of smart munitions. The first generation of smart weapons provided cluster munitions capable of autonomous target detection, while the second generation will have the seeker capability to classify and—in some cases—identify targets. This classification and identification permits the use of smaller advanced warheads with real-time modifying kill mechanisms that enable lethality against a broad range of targets and smaller overall weapon size.³³

Presently the USAF is evaluating numerous AMM weapon concepts in an attempt to identify the most cost-effective and risk-reduced weapon system that will meet mobile target miniature munition requirements. These weapon concepts include but are not limited to Low Cost Autonomous Attack System (LOCAAS), Brilliant anti-armor submunition P3I (BAT), Ringneck, Extended Range Autonomous Attack System, Power Submunition, and the MMC-150. Many of these MMC weapon concepts provide a standoff capability against fixed, relocatable, and mobile targets in addition to multikills per pass, controlled weapon effects, internal and

external carriage loadouts, increased aircraft loadouts, adverse weather precision guidance, and collateral damage reduction.

Low Cost Autonomous Attack System

The LOCAAS was started as an advanced development engineering effort to provide a technology base for future low-cost LADAR sensor submunitions. It has become a miniature, powered munition capable of broad area search, identification, and destruction of a range of mobile targets. In its present form, LOCAAS is an 85-pound turbojet-powered munition that incorporates a LADAR seeker with a multimode warhead and a maneuvering airframe to produce a high-performance munition against mobile targets. The LADAR seeker provides autonomous target detection, target identification, aim point selection, and information for warhead selection capabilities. The warhead can be detonated as a long-rod penetrator, an aerostable slug, or as fragments based on target identification and classification. A GPS guidance and inertial navigation system provides very accurate midcourse guidance which aids LADAR seeker search performance. The LOCAAS has an endurance of 30 minutes, a standoff range of 100 NM and a preplanned search capability. The LOCAAS's endurance is inversely related to its standoff employment range. Planned features include the capability of four LOCAAS munitions to search a 100-square-NM area within 30 minutes.³⁴ The LOCAAS weapon system will have a data-link capability with other LOCAAS submunitions, which will enable integrated search and attack operations. The LOCAAS submunitions will have the capability to be dispensed from an aircraft or UCAV by an external TMD, an internal dispenser, an internal weapon bay carriage, a munition ejector, and an external pylon. In addition, the Army Tactical Missile System (ATACMS) or the Multiple Launch Rocket System could employ the weapon system.³⁵

Brilliant Anti-Armor Submunition

A weapon system that is currently employed by the US Army's ATACMS, which is being considered as an MMC weapon concept, is the BAT. The initial production BAT is an acoustic and IR seeker-guided submunition that autonomously detects, tracks, and destroys mobile targets.³⁶ The MMC BAT weapon system concept is a P3I version that retains the basic physical characteristics of the BAT submunition but incorporates a dual-mode IIR/MMW seeker. This seeker will improve overall target detection and classification and enable the employment of a multimode warhead that increases probability of kill and reduces collateral damage. Integration on USAF aircraft could be through the JSOW dispenser weapon.

Other MMC Concepts and Issues

Other MMC concept weapon systems have characteristics and capabilities similar to LOCAAS or BAT. These characteristics and capabilities include

standoff employment ranges, high aircraft loadouts, ATA, GPS/INS mid-course guidance, multimode warhead, and either a glide or power flight profile. The ATA systems are based either on a LADAR or IIR/MMW seeker that provide target detection, identification and classification, and precision guidance. Descriptions and characteristics of specific weapon concepts are unavailable due to contractor proprietary information concerns related to the ongoing MMC program. Because many of these weapon concepts provide similar capabilities using similar seeker and guidance technologies, they are referred to as "LOCAAS-like weapons."³⁷ The term *LOCAAS* is used because it is the most well-known MMC acquisition program.

These LOCAAS-like weapons and their associated ATA capabilities address many of the key shortfalls in current and near-term USAF PCS operations against mobile targets. The main focus of ATA technologies and these weapon systems is overcoming target location errors and target location uncertainty associated with mobile targets as well as providing target identification capability. Once a weapon is launched, current off-board sensors and guidance systems are limited in their ability to overcome TLEs and TLUs while providing precision guidance accuracy. Some autonomous weapon seekers have the ability to overcome TLE and TLU but lack target identification capabilities. Their image processing cannot identify the target but is adequate to provide guidance updates to overcome TLE and TLU on the target. However, when engaging mobile targets in a high-risk collateral damage environment, all three requirements—TLE, TLU, and target identification—must be met. Presently, the only weapon systems that provide a limited capability for meeting all three of these requirements are those weapon systems with MITL guidance.

The highest technical risk associated with the LOCAAS and other LOCAAS-like programs is the ATA capability. These ATA systems must be able to identify and discriminate between targets and nontargets, to include mobile missile launchers, tanks, military personnel carriers, and noncombatant vehicles. In addition to this tremendous task, these systems must be able to guide the weapon to the target and provide target data for precise warhead aim point and multimode warhead selection. Of these ATA systems, LADAR appears the most promising seeker technology. LADAR offers high-resolution, high-accuracy 3-D active imagery, large-area search, real-time ATA and real-time target tracking. The prototype units are approximately seven inches in diameter, seven inches long, and weigh approximately 10 pounds. If purchased with high-volume production, the seeker is expected to cost \$12,000 per unit.³⁸

Captive and free flight testing of a LADAR seeker has demonstrated a 99 percent probability of acquiring mobile or relocatable targets with a 95 percent probability of classifying the target in real time.³⁹ Current algorithms use range and angle data for target acquisition and classification. The seeker collects 3-D data with six-inch resolution. While yielding higher probability of target acquisition and classification, the ATA system requires no extensive signature database to define targets of interest. De-

developmental tests have demonstrated the ability of LADAR to see through low rain rates, most fog conditions, camouflage nets, and most battlefield smoke obscuring agents.⁴⁰ LADAR's target classification ability has enabled multimode warhead capabilities that maximize probability of kill while reducing the risk of collateral damage.

Future LADAR capabilities could include a new pulsed laser for use in a focal plane array (FPA) LADAR seeker. The advantages of an FPA are increased frame rates, wide instantaneous FOV, and the elimination of mechanical scanning mechanisms, resulting in reduced cost and increased maintainability.⁴¹ In addition, techniques and components that use near-IR to mid-IR wavelengths are being researched and developed in hopes of producing a more eye-safe LADAR system which could further minimize collateral damage. All USAF LADAR research efforts are focused on providing a low-cost small package system for autonomously guided air-dropped munitions.⁴²

An ATA seeker that provides target identification and precise warhead guidance is the critical system on which all of the MMC weapon concepts depend. A LADAR-based ATA seeker supports many MMC requirements and has shown promising test results. Due to these factors, a LADAR or similar seeker system that provides ATA is the keystone to the near-term USAF PCS capabilities against mobile targets. However, there is technological risk associated with any ATA capability. The key role ATA technology—specifically LADAR-based systems—plays in providing a PCS capability against mobile targets demonstrates the extreme risk associated with a weapons acquisition strategy that is focused on only autonomous-guided weapon systems. If the MMC program and associated ATA R&D does not produce a PCS capability against mobile targets within the next five to 10 years, the USAF will have to rely on current precision weapon systems—with their PCS limitations against mobile targets—for the next 10 to 15 years. Realizing this, the USAF is taking steps in hopes of minimizing the risk associated with the acquisition of an MTMM and the required ATA technology.

Presently, the Munitions Directorate Assessment and Demonstrations Division of the Air Force Research Laboratory is conducting an advanced technology demonstration (ATD) of the LOCAAS program. The overall objective of the ATD is to provide and demonstrate the technology to produce an affordable standoff (minimum 90 miles) miniature munition that autonomously searches for, detects, identifies, attacks, and destroys mobile targets and that is also able to discriminate between military targets and noncombatants. Specifically, the ATD hopes to demonstrate that a low-cost (\$30,000 per munition) system can be produced incorporating a multimode warhead, a solid-state LADAR seeker with an ATA capability, and a GPS/INS midcourse guidance system into a turbojet-powered air vehicle.⁴³

Additionally, all key program phase point decisions for LOCAAS-like weapon systems—to include engineering and manufacturing development (EMD)—will be heavily influenced by the USAF and contractor's assessment of ATA measures of performance (MOP).⁴⁴ ATA MOPs will evaluate

the probability of target identification errors, false target attack rate, the probability of engagement success, and CEP. Presently, LOCAAS ATA performance is meeting or exceeding all MOPs. An EMD decision on LOCAAS has been delayed until 2005, and the funding during the program definition and risk reduction (PDRR) phase has been increased to reduce the risk associated with the MMC program. However, this delay in EMD and increased PDRR funding will further delay the acquisition of an operational capability that is needed today. At the present time, the earliest a LOCAAS-like weapon will be operational on a USAF aircraft is 2010.⁴⁵

Conclusion

The USAF's strategy to leverage present and future sensor and guidance technologies to overcome limitations in current PCS operations against mobile targets in high-risk collateral damage environments is sound and justified. However, an analysis of these near-term sensors and weapons and their related technologies reveals that many of these systems will not be operational for another 10 to 15 years. In addition, there are technological risks associated with many of these sensor and weapon systems that could delay their acquisition or reduce their operational effectiveness. During the next 10 years, the USAF will be called upon to provide a PCS capability against mobile targets in a high-risk collateral damage environment. Presently and in the near term, the only weapon system that will be able to provide this capability within the next two to three years is a next generation data-link MITL guidance standoff weapon that overcomes present MITL guidance weapon limitations. Future sensor and guidance technologies must continue to be pursued. However, to meet today's operational shortfalls in PCS operations, resources must be invested in weapon systems and technologies that will quickly provide the USAF with a PCS capability against mobile targets.

Notes

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Chapter 5

Legal Issues, Accountability, Flexibility, Science and Technology Shortfalls, and Acquisition Risk Management

So by the benefit of this light of reason, they have found out Artillery, by which warres come to a quicker ends than heretofore, and the great expense of bloud is avoyed; for the numbers slain now, since the invention of Artillery, are much lesse than before, when the sword was the executioner.

—John Donne, 1621

The research, development, and acquisition of airpower weaponry creates, affects, and is influenced by numerous issues and factors in the strategic environment. The USAF's weapon research, development, and acquisition strategy must consider and address the legal issues, accountability questions, operational flexibility, S&T funding shortfalls, and acquisition risk management as it attempts to provide a PCS capability against mobile targets. The use of autonomous weapons may create legal issues that may not be acceptable to military or civilian leadership and may not provide the level of accountability required in a military operation. Autonomous operations are greatly affected by the ROEs associated with the military operation. MITL-guidance weapons could provide the flexibility and acquisition risk reduction needed in today's strategic environment. There may be no clear answer to the question of manned versus unmanned military weapons systems. However, this analysis of key issues and their influence on current and near-term USAF PCS operations will demonstrate a need for an MITL-guided weapon system.

Legal Issues

In his report *Technology and the 21st Century Battlefield: Recomplicating Moral Life for the Statesman and the Soldier*, Charles Dunlap posed a legal question regarding PGM use and acquisition. He asked, "To what extent must a nation's people sacrifice in order to acquire systems to protect enemy civilians?"¹ He further states, "It could be argued that simply having PGMs mandates their use under the theory that the commander has an available alternative that can save noncombatant lives."² Dunlap expresses the accepted view that there is no obligation to use PGMs as long as the tenets of the law of armed conflict are observed and that the commander can consider the price of the weapon as a factor in choosing the means of attack.³ However, this may not always be the accepted view or norm.

The perception that PGM use greatly minimizes collateral damage may create a new precept in the court of world opinion, and a paradigm might

be created that assumes the United States has the ability to employ military force through the use of PGMs with minimal or no collateral damage.⁴ This new paradigm could create the perception that the failure to use PGMs represents a US decision to cause collateral damage and noncombatant deaths.⁵ Dunlap states, "If this perception comes to represent the consensus of world opinion, it is not inconceivable that international law may someday *require* PGM use (as well as other high-tech instrumentalities) by those nations with the resources to produce or acquire them."⁶

This issue is further complicated by the enemy's efforts to defeat high-tech precision-guided weapons. The use of PGMs may drive an adversary to employ pernicious methodologies to counteract them.⁷ Because high ethical standards are central to America's military ethos, the United States is vulnerable to tactics that attempt to exploit their innate respect for human life.⁸ Iraqi and Serbian forces routinely and purposely placed military resources and civilian noncombatants in close proximity of each other during Desert Storm and Allied Force operations in hopes of negating the United States's PGM capabilities. The effectiveness of PGMs has caused frustrated adversaries to clearly violate international laws and norms. The use of PGMs may put more noncombatants at risk due to the action of unscrupulous adversaries who are trying to counter technologically superior weapons with the age-old strategy of human shields.⁹ Even the most advanced PGMs will cause unintended noncombatant casualties against this type of military strategy. However, an MITL-guided weapon could provide a greater capability to limit these casualties when compared to autonomous-guided weapons.

No precision-guided weapon can accurately and reliably identify noncombatants in close proximity of a military target. However, an MITL data-link guidance weapon does provide—though limited—a capability to detect and identify noncombatants. Autonomous-guided LOCAAS-like weapons cannot detect or even differentiate combat versus noncombatant personnel. In addition, autonomous systems cannot "assess" the target area and acquire critical "situational awareness" of the target environment. An MITL system provides real-time target area intelligence and a limited capability to detect and assess the possibility of noncombatant casualties. In what could be considered a "worst case," densely populated urban environment, an MITL-data-link guided weapon provides the greatest collateral-damage minimizing capability when attacking mobile targets. The destruction of mobile military forces in an urban environment may not be a routine mission for the USAF, but it is a precision engagement capability that will no doubt be required in future conflicts.

The Accountability Question

Related to the legal issue is the question of accountability. If a society becomes more sensitive to death, destruction, and collateral damage as the information age provides real-time military operations reporting, will a nation's government and general public demand more accountability in

airpower operations?¹⁰ If accountability is demanded by US civilian leadership, it is not likely this accountability will be entrusted to anything else but a human. Since military operations involve decisions or actions that could result in intentional or unintentional death and destruction, a human must be accountable.¹¹ Autonomous weapon systems only have a limited capability when compared to MITL systems to acquire real-time information or react to internal system malfunctions.¹² These limitations could increase the probability of collateral damage. A human is not required in all PCS operations, but in the destruction of mobile targets in a high-risk collateral threat environment, one must be involved in target selection and weapon delivery decisions.¹³ As in air-to-air operations, when militarily sound and physically feasible, ROEs for PCS operations against mobile targets should favor visual target identification over autonomous target identification.¹⁴ An MITL system does not guarantee 100 percent accuracy or reliability, but it does provide 100 percent accountability. This accountability may be the critical factor that maintains public support of a military operation or holds a fragile military coalition together in the aftermath of a collateral damage incident.

Flexibility and Risk Reduction

A research, development, and acquisition strategy that supports an MITL weapon system will not only provide a needed PCS capability against mobile targets but will positively address critical flexibility, S&T funding, and risk issues associated with USAF weapon acquisition programs. Today's uncertain strategic environment requires flexibility in military operations. An MITL weapon would greatly improve the USAF's overall air-to-ground capabilities and flexibility. Reductions in S&T budgets have negatively affected technological advances in target identification and weapon guidance, which in turn have delayed the acquisition of an autonomous weapon system capable of identifying and destroying mobile targets. An MITL weapon could provide a PCS capability until S&T shortfalls in these areas can be overcome. In addition to overcoming technology delays, the acquisition of an MITL weapon would reduce the risk associated with these future autonomous weapons.

The USAF is embracing a recent military technological innovation—autonomous guided air-to-ground weapons—while reducing and eliminating other guided air-to-ground weapons, particularly MITL weapons. Given the uncertainty of future conflicts, should the USAF pursue this particular military innovation strategy? Rosen states that, "The fundamental problem of managing military research and development is that uncertainties about the enemy and about the costs and benefits of new technologies make it impossible to identify the single best route to innovation."¹⁵ To deal with these uncertainties, Rosen suggests the development of a flexible strategy instead of an optimum strategy. Rosen also states, "A strategy for military technological innovation that seeks as much flexibil-

ity as it can buy might be better than one trying to buy the one weapon that would perform the best if it could be built to specifications at the expected cost and if it eventually turned out to be the weapon which was actually needed."¹⁶ This strategy of flexibility is more appropriate in today's strategic environment than ever before.

The United States has entered and will probably remain in a period that presents many opportunities and challenges. This strategic environment will create a very dynamic and uncertain national security environment for the US military. The challenges will include but are not limited to regional, asymmetric, and transitional threats to US national interests.¹⁷ The environment will remain uncertain with unknown and unpredictable adversaries. US military forces will be involved in a variety of operations across the spectrum of conflict to include limited strikes, SSCs, major theater wars, and global conflicts. These operations will be characterized by continual changes in technology and increased coalition military operations to address threats to US national interests. Political and social interests may demand these military operations be executed with minimal collateral damage to friendly and enemy forces. Simultaneously, the US military has experienced a rapid reduction in its budget and a corresponding reduction in force structure. Therefore, considering all these factors, the strategic environment in which the US military will be required to operate will be dominated by uncertainty.

During this period of "military operations uncertainty," the USAF's focus on autonomous-guided weapons will reduce its precision engagement flexibility and does not support a "Type I" flexibility strategy that Rosen recommends as a way to manage uncertainty.¹⁸ Type I flexibility is the acquisition of weapons that, while not optimal for a single given scenario, would be useful in almost all contingencies. MITL weapon systems have proven their Type I flexibility in numerous air operations against a variety of targets. MITL weapon systems have been used in CAS, suppression of enemy air defenses, counterland, countersea, theater missile defense, and weapons of mass destruction counterproliferation operations against mobile and fixed targets. Autonomous weapons are not as flexible because of their limited ability to acquire real-time information and their inability to acquire situational awareness of the target environment. Rosen does state that Type I flexibility may be impossible or prohibitively expensive. However, this is not the case in the acquisition of an MITL guided air-to-ground weapon in quantities that would greatly improve the USAF's overall precision engagement capability and flexibility.

Current USAF data-link MITL-guidance weapons, while more flexible than current autonomous systems, have limitations in the identification and destruction of mobile ground targets. However, many of these limitations can be overcome at relatively low cost and low technological risk. Today's limitations include limited FOV and FOR seekers, marginal seeker performance, no loiter capability, no go-around capability, and no video playback capability. Overcoming these shortfalls requires no unproven

technology and would be relatively inexpensive compared to autonomous weapon R&D costs. An MITL-guidance weapon with increased FOVs and FORs and loiter/go-around/video playback capabilities could be produced at a unit cost of \$200,000.¹⁹ The addition of such a weapon to the USAF air-to-ground inventory would not only dramatically improve its PCS capabilities against mobile targets but would greatly prove its overall air-to-ground flexibility at a funding level that would not threaten autonomous system research.

Science and Technology Funding Shortfalls

An MITL weapon system will not only provide the USAF the flexibility needed in today's uncertain strategic environment, it will also address S&T funding shortfalls that have caused delays and increased technology risk associated with autonomous weapon identification and guidance capabilities. A report published by the Air Force Association's (AFA) S&T committee stresses that declines in research and advanced technology development funding have and will continue to reduce future USAF operational capabilities. This decrease in funding has delayed seeker, guidance, and processing advances required for autonomous-guidance weapons. These delays and technology shortfalls will inhibit the USAF from acquiring an autonomous weapon PCS capability against mobile targets in the next 10 years. If funding does not dramatically increase, the USAF will have to acquire this PCS capability with current and proven technologies, specifically MITL weapon systems.

S&T funding reductions have delayed critical technology advances and created an emphasis on "requirements pull" weapons research approach instead of a more balanced and effective "technology push/requirements pull" approach. The AFA S&T committee's report noted that the USAF has gone from first to last among the armed services in S&T funding. Since 1989 the USAF budget for R&D has been cut in half. The report stressed that the USAF has reduced R&D funding to pay for day-to-day operational funding needs brought about by increased operational requirements. In addition, the committee perceived a lack of commitment to the R&D of technologies that did not support or address current or near-term weapon requirements or programs.²⁰ This short-term focus resulted in an R&D strategy that concentrated on PCS capabilities against fixed targets, and only recently has the USAF addressed PCS capabilities against mobile targets. This R&D funding strategy has delayed the development of critical seeker and guidance technologies required for an autonomous weapon capability against mobile targets. On the surface, the acquisition of an MITL weapon system may appear to support a short-term S&T strategy; however, it could result in a more balanced requirements pull and technology push R&D strategy.

A requirements pull occurs when doctrine, strategy, or operational requirements are the driving factors in technological developments and in-

novations. During a technology push, technological developments and innovations are not tied to a stated requirement; but their creation may foster new doctrine, strategy, or operational capabilities or ideas. There are advantages and disadvantages associated with each; however, the preferred R&D strategy is typically based on a combination of both approaches. The AFA's report stresses that due to declines in S&T funding, the USAF is at risk of becoming trapped in a requirements pull strategy that could result in the inability of technology to meet future unidentified operational requirements in a timely manner. A requirements-pull-only strategy will force R&D to focus on technologies that may provide a quick but partial solution to operational requirements and ignore slower developing technologies that may provide a more complete and long-term solution. A balanced strategy is ideal because it meets near-term and far-term requirements, rather than only partially meeting near-term operational requirements. In the area of autonomous weapon capabilities against mobile targets, the USAF's R&D strategy is unbalanced. Technology is being pulled to meet operational requirements, and there are very few far-term innovations to reduce the risk associated with future autonomous weapon technologies.

The report points out that S&T initiatives can take decades to mature and provide operational capabilities and that many of the current weapon systems were only possible because of technology investments made in the 1960s, 1970s, and 1980s. During the past decade, funding decreases have caused many promising and critical technologies—including miniaturized munitions—to be constrained and delayed. This delay in technological advances has resulted in the improbability that the USAF will produce an autonomous weapon capability against mobile targets in a high-risk collateral damage environment within the next decade without drastic funding changes.

The acquisition of a new or improved MITL weapon system would provide a PCS capability against mobile targets while allowing a more balanced S&T strategy. The acquisition of an MITL weapon system that incorporates mature and proven technology would not rely on current or future basic S&T efforts or resources. As a result, an MITL weapon system could be acquired with operational system development or foreign military system acquisition funds and thus would not negatively affect S&T research funding and efforts supporting autonomous weapon capabilities. Therefore, the acquisition of an MITL system would meet a critical requirement while providing the time and resources needed to develop a more capable autonomous weapon system. The resources used to acquire a new or modify a current MITL weapon system would reduce the funds available for the acquisition of other USAF weapon systems. However, it would not drastically affect the USAF's overall PCS capability. With an apparently robust PCS capability against fixed targets, the funding of a weapon system with a PCS capability against both fixed and mobile targets would be economically feasible and operationally smart. Therefore, to

overcome past and probable future R&D funding shortfalls and provide an interim PCS capability against mobile targets, the USAF should set its sights on an MITL weapon system that incorporates proven technology. This recommendation of interim MITL weapon systems to overcome delays in technology development and maturation is not intended to carry the past into the future rather than innovate new autonomous weapons. The main objective would be to quickly provide a critically needed PCS capability with minimum R&D resources.

The critical issue the AFA committee addressed was whether or not USAF R&D funding would be able to deliver the technology needed to counter the threats of the future. In the area of autonomous weapons, technology has not yet delivered a capability against mobile targets. S&T funding shortfalls have not only delayed the development of autonomous weapon systems but will also increase the risk associated with autonomous weapon programs that are trying to overcome the USAF limitations in executing PCS operations against mobile targets.

Acquisition Risk Management

The acquisition of an MITL-guidance weapon system will not only provide needed PCS capability against mobile targets in high-risk collateral damage environments but will also reduce the risk associated with future autonomous-guidance weapons through the employment of acquisition reform "best practices." In recent years DOD has implemented several acquisition initiatives that draw lessons from commercial practices, such as Cost as an Independent Variable and Integrated Product teams. The reduction in S&T funding in the USAF will negatively affect the maturity of sensor, seeker, and guidance technology required for an autonomous weapon capability against mobile targets. This immaturity in autonomous weapon technology will add risk to present and future weapon system programs attempting to overcome USAF PCS shortfalls against mobile targets. These funding-induced risks may be overcome by acquisition reform initiatives that acquire weapons better, faster, and cheaper.

Acquisition reform has been taught as the silver bullet that will allow the acquisition of high-tech weaponry during today's tight defense budget. Many of these acquisition reform initiatives focus on commercial best practices and the application of these to the defense sector. Commercial practices do not automatically transfer to the defense sector, but the principles and strategies on which these practices are based can demonstrate ways for the USAF to make similar improvements in weapon acquisition. A commercial practice highlighted by Katherine Schinasi and others in "Applying Best Practices to Weapon Systems Takes the Right Environment" that could improve the USAF's weapons acquisition is the attainment and execution of key product knowledge points early in an acquisition program.

In commercial product development, the placement of “key knowledge points” drastically influences the risk associated with product acquisition. Key knowledge points are those points in an acquisition process when the decision makers have reached virtual certainty about aspects of the product being developed.²¹ The authors stress that the attainment of key product knowledge early in an R&D program is critical to program risk reduction and overall success. Key knowledge points occur early in commercial programs; but in DOD product development, key knowledge points are deferred until late in the program (fig. 2). These delays push the discovery and resolution of unknowns, which could include the maturity of technology, into the production phase. Gaining knowledge earlier in program development enables a system to meet performance and producibility requirements and reduces system risk. However, the DOD acquisition process is notorious for gaining knowledge late in program development. In many DOD acquisition cycles, a weapon system program is started during technology development.

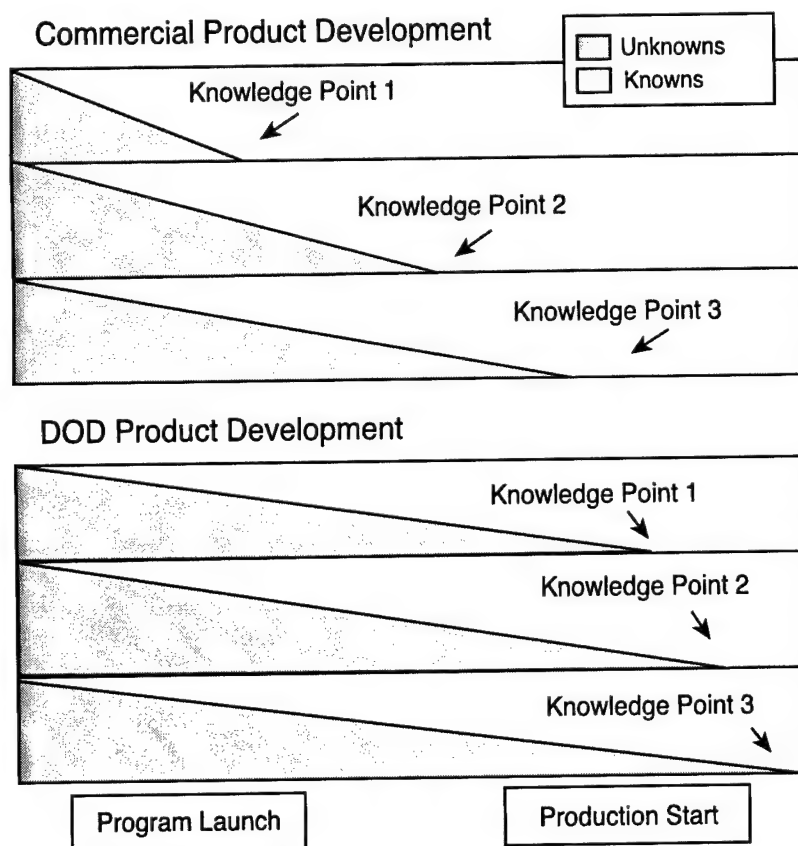


Figure 2. Comparison of Three Key Knowledge Points for Commercial and Military Product Development

The different acquisition and risk management approaches taken by the commercial sector and DOD are due to the way each defines success and failure. Success in a commercial program is determined by the amount of profit the firm makes on items sold to customers. Failure is defined as the customer buying a competitor's product. Because program success is determined in production when the customer buys the finished product, commercial programs are less likely to accept technology or design features that may improve product performance if it cannot be proven there will be no changes to product cost, quality, or quantity targets. The definition of success in a DOD program is complicated by the fact that the point of sale begins at the very beginning of program development when competition encourages overpromising performance while underestimating cost and schedule. Therefore, due to a competition for funding, risk in the form of ambitious technology advancements and tight cost and schedule estimates are accepted in the DOD acquisition process as a necessity for program launch. Success occurs throughout program development as the US government pays for the product on an installment basis. By the time production begins, the customer—the US government—is so deeply invested that it is unlikely to walk away.²² As a result, success in a weapon system program is substantially determined early in the program development and not when the final product is placed in the war fighter's hands. Weapon system success should be determined on what the product actually delivers, not what it promises to deliver.

The risk associated with the development of a weapon system is directly related to the successful management of cost, schedule, and performance. Schinasi and others point out that the management of these factors is directly related to the knowledge of critical aspects of weapon development and production. In the acquisition process, knowledge is the inverse of risk. Three key knowledge points have been identified: (1) when a match is made between the customer's (weapon) requirements and available technology; (2) when the weapon product's design is determined to be capable of meeting performance requirements; and (3) when the product is determined to be producible within cost, schedule, and quality goals. Schinasi and others insightfully identified that these knowledge points are applicable to both commercial and DOD product development cycles, but *where* the knowledge points occur is very different.

Knowledge Point 1 is defined when a match exists between available technology and production requirements. This point occurs when product requirements can be met without depending on immature technology. A technology is mature when there is proof it will work and can be produced at an acceptable cost, on schedule, and with high quality. Unlike commercial acquisition practices, Schinasi and others identified that some DOD programs do not attain this match between technology and system requirements at the time that a program is launched. Furthermore, it was discovered that many DOD weapon programs are launched during technology development. This practice of launching a program during tech-

nology development greatly increases the technological risk associated with the acquisition program.

Knowledge Point 2 is defined when it is felt the design will work. This point is met when the required percentage of engineering drawings are available for critical design review. Schinasi and others pointed out that the completion of engineering drawings in conjunction with critical design reviews (CDR) demonstrates the confidence in a system's design and the technology maturity required to meet system requirements. Both DOD and commercial sectors perform CDRs to review engineering drawings, determine design maturity, and to "freeze" technology, performance, and system requirements in product design. In addition, both sectors consider a design to be complete when 90 percent of the engineering drawings are completed. However, DOD typically performs CDRs prior to this level. DOD has performed CDRs with less than one-third of the engineering drawings completed, and many programs do not reach the 90 percent level until the customer has received several production weapon systems. This system development practice has caused several technical problems associated with a system's performance and has resulted in extensive redesigns, cost increases, and scheduling delays.

The third knowledge point occurs when production units meet cost, schedule, and quality goals. While commercial acquisition practices require a very high confidence that the manufacturing process will be able to produce a product within cost, quality, and schedule requirements before starting production, DOD acquisition practices require a lower confidence level in system producibility when production is started. The acquiring of producibility late in a program's development once again causes cost, schedule, and quality problems.

The acquisition of an MITL system, in which all three key knowledge points are known, will provide the USAF with a critically needed PCS capability against mobile targets while allowing future autonomous-guidance weapon programs to attain key knowledge points earlier in their overall acquisition process. Specifically, the acquisition of an MITL system would permit a better match between autonomous weapon technology and autonomous weapon requirements to occur before a program is launched. Furthermore, it would allow a greater percentage of engineering drawings to be completed at CDR regarding autonomous weapon systems and thus reduce the risk of system redesign, cost increases, and scheduling delays. In addition, it would allow future autonomous weapon programs to attain required key producibility knowledge. These advantages would result in the movement of all three key knowledge points to the left in relationship to the overall autonomous weapon acquisition program. These actions could delay the acquisition of an autonomous weapon system, but it would greatly reduce the risk associated with the acquisition program. A newly acquired interim MITL weapon would fill the operational PCS shortfall caused by this delay.

Precision capabilities against mobile targets in high-risk collateral damage environments must not hinge on overpromised performance and underestimated resource requirements. The USAF's desire for autonomous weapons could pressure weapon development programs to embrace technological advances that cannot be reasonably delivered. Schinasi and others recommend that this pressure be reduced by separating technology development from product development and by pushing program launching points to a point where technology development is mature. Also, if a technology is pulled in the area of autonomous weapon systems but it does not deliver the required operational capabilities in the area of mobile targets, the USAF could find itself without any PCS capability against mobile targets. There are many technological risks associated with autonomous weapons for PCS operations. The acquisition of an MITL system would allow new autonomous system production decisions to be delayed, thus enabling a more balanced technology push/pull approach and providing the opportunity to address technology risks before a weapon program is launched, not during weapon production.

Conclusion

This analysis of legality, accountability, operational flexibility, S&T funding shortfalls, and acquisition risk management issues has not provided a universal answer to the manned versus unmanned question in regard to military weapon systems. However, it has demonstrated a need for an MITL-guided weapon system to overcome current limitations in USAF PCS capabilities against mobile targets. The use of autonomous weapons may create legal issues that may not be acceptable to military or civilian leadership who desire accountability in military operations. Autonomous operations are greatly affected by the ROEs associated with military operations. MITL-guidance weapons could provide the flexibility and acquisition risk reduction needed in today's strategic environment. An MITL system could also minimize the negative effects of technology maturation delays on PCS capabilities brought about by USAF S&T funding shortfalls. Finally, an MITL weapon would allow technology for autonomous weapon capabilities to mature to a level that will reduce the risk in the acquisition of future autonomous PCS weapons. A research, development, and acquisition strategy that includes MITL weapon systems would not only provide a PCS capability against mobile targets but would provide this capability in a strategic and acquisition environment that demands "doing more with less."

Notes

1. Charles J. Dunlap Jr., *Technology and the 21st Century Battlefield: Recomputing Moral Life for the Statesman and the Soldier* (Carlisle Barracks, Pa.: Strategic Studies Institute, US Army War College, 15 January 1999), 16.

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21. Katherine Schinasi et al., "Applying Best Practices to Weapon Systems Takes the Right Environment," *Program Manager*, January-February 2000, 4.
22. Ibid., 6.

Chapter 6

Conclusions and Recommendations

Air Forces must harmonise their equipment with their doctrine but keep their vision far into the future.

—Air Vice-Marshal Tony Mason

Precision engagement has been and will continue to be the Holy Grail of airpower and airmen. Improvements in airpower precision engagement have been remarkable during the past century; however, recent airpower operations have revealed a deficiency in airpower's ability to precisely attack mobile targets and fielded forces in a complex political-military collateral damage sensitive environment. The inability to identify and precisely destroy military targets in close proximity of noncombatants is the main cause of this deficiency. In addition, this shortfall in precision engagement capabilities is an obvious airpower vulnerability to present and potential adversaries that will be exploited through asymmetric strategies. This weakness in precision engagement capabilities, in conjunction with the political and military leadership's desire to minimize collateral damage and an adversary's exploitation of this sensitivity, could limit the effectiveness of future US airpower-focused military operations. At the same time, the USAF's weapon research, development, and acquisition strategy is focusing on autonomous weapon systems while excluding MITL systems, thus reducing airpower's inherent flexibility and adaptability.

The analysis of the current strategic environment, political guidance, military operational doctrine, and recent airpower operations revealed their complex interaction and influence on USAF armament R&D and the critical need for PCS capabilities against mobile targets. The strategic environment today and over the next two decades will create challenges for the USAF armament R&D strategy. USAF armament funding will remain static and continue to represent a small percentage of future DOD and USAF budgets. Future airpower operations will cover the full spectrum of war to include MOOTW. The USAF's ability to provide the freedom to attack and freedom from attack will be challenged by advanced technology ground systems that will be transportable, relocatable, mobile, and very agile. US military operations will be based on achieving the culminating point early in a conflict and providing a variety of responsive executable courses of action for its political and military leaders. In addition, US military forces are becoming lighter, leaner, and more lethal in an effort to support military operational concepts against a technologically advancing threat across the entire spectrum of war. Political aspects and realities will continue to influence US military weapon modernization programs. In light of and in response to these issues and stated joint and USAF doctrine, USAF armament R&D must acquire weapon

systems that when called upon will provide the capability to apply selective force against mobile targets with discrete and discriminant effects.

Recent military operations are evidence of the importance and the steadily improving effectiveness of airpower in achieving national, political, and military objectives. Airpower's precision engagement capabilities—specifically USAF capabilities—are the main reasons for this importance and effectiveness. Minimizing collateral damage is becoming a rule of modern warfare; therefore, airpower strategies, operations, and weapons R&D must treat this issue honestly and explicitly. Today, airpower's inherent versatility, flexibility, and responsiveness are linked in large part to its precision engagement capabilities. Any reduction or failure to improve precision engagement capabilities will reduce the inherent abilities and strengths of airpower.

The USAF has a vast array of guided air-to-ground weapons which enable very effective and efficient PCS operations against fixed ground targets. However, in execution of one of the most difficult tasks in air-to-ground operations—the destruction of small, very mobile targets in adverse weather with a strong air defense in a high-risk collateral damage environment—these weapons provide only limited capabilities. Presently, LGBs, the GBU-15, the AGM-130, and the AGM-65 MITL weapon systems provide the greatest PCS capabilities; however, these systems have limitations. Airborne-designated LGBs have adverse weather and standoff limitations, while the LANTIRN system has only a marginal target identification capability that is greatly dependent on employment tactics. The GBU-15 has limited all-weather and standoff capabilities; but even with precision guidance, its large warhead could cause considerable collateral damage. Its lack of loiter and go-around flight profiles greatly limits its target identification capabilities. Except for greater standoff ranges, the AGM-130 and AGM-142 have the same limitations as the GBU-15. The AGM-65 has a much smaller warhead than the GBU-15, AGM-130, and AGM-142; but it has a limited standoff range and no target identification or update capability after release.

Current USAF GPS-guided autonomous weapons are limited in their ability to meet target identification requirements and location uncertainties associated with mobile targets. TLE and TLU will continue to limit GPS-guided autonomous weapon effectiveness. Seeker advances may ultimately overcome these limitations, but current seeker technologies have only demonstrated the ability to identify large strategic fixed targets. A few seeker technologies have demonstrated an identification capability against stationary mobile targets, but these technologies will not be operational within the next 10 years. Presently, no USAF operational air-to-ground weapon system has an autonomous target acquisition capability against mobile targets.

The USAF's strategy to leverage present and future sensor and guidance technologies to overcome limitations in current PCS operations against mobile targets in high-risk collateral damage environments is sound and justified. However, the analysis of these near-term sensors and weapons

and their related technologies reveals that many of these systems will not be operational for another 10 to 15 years. In addition, there are technological risks associated with many of these sensor and weapon systems that could delay their acquisition or reduce their operational effectiveness.

An analysis of legality, accountability, operational flexibility, S&T funding shortfalls, and acquisition risk management issues demonstrated a need for an MITL-guided weapon system in regard to providing a PCS capability against mobile targets. The use of autonomous weapons may create legal issues that may not be acceptable to military or civilian leadership. Autonomous weapons may not provide the appropriate amount of accountability in military operations. Autonomous operations will be greatly affected by the ROEs associated with the military operations. MITL-guided weapons could provide the flexibility and acquisition risk reduction needed in today's strategic environment.

Is there a "single best route" the USAF should follow in its research, development, and acquisition of a weapon system that will provide it with a PCS capability against mobile targets as Rosen suggests? Clearly, there is no single best strategy or weapon that the USAF can follow or acquire that will provide a PCS capability against mobile targets in a manner that is completely appropriate with today's strategic environment. The USAF will have to balance the need for future capabilities against today's realities. The creation, selection, and execution of weapon research, development, and acquisition strategies that address future requirements while meeting today's realities are challenging exercises in risk management.

Current USAF weapons research, development, and acquisition places an emphasis on the emergence of autonomous-guidance precision weapons within the next five to 10 years to overcome shortfalls in its PCS capabilities against mobile ground targets. There should be concern over the amount of risk associated with the emerging technologies that will provide this autonomous capability and the neglect of MITL weapon systems at the expense of these brilliant weapons. The USAF may be creating a "window of risk" for the next several years by focusing on autonomous weapons and not bolstering or improving current generation precision-guided weapons. The USAF may be "overreacting to the lure of new technologies and placing all of its eggs in a single fragile basket, without due attention to the budgetary and technical pitfalls that still lie ahead."¹ However, if USAF leaders believe Gen Joseph W. Ralston's statement, "We (USAF) can do the job we are asked to do with acceptable risk," then the USAF should continue with its current autonomous-guided weapon strategy.² But if the risk of collateral damage and its effect on near-term airpower operations are unacceptable, the USAF needs to modify its weapon acquisition strategy to include the acquisition of an MITL-guidance precision weapon capability.

Any acquired or modified MITL weapon system must overcome current limitations in USAF MITL weapon systems. These limitations include limited FOV and FOR, no loiter or go-around capability, marginal seeker performance, and no cockpit video playback capability. To minimize the ac-

quisition time line, the USAF should first attempt to acquire a currently operational US or foreign MITL weapon system. If no such weapon system is available, an operational system—US or foreign—should be acquired and modification made to overcome any of the previously mentioned limitations. The USAF should not develop a new MITL weapon system due to the extended weapon acquisition time line typically associated with military acquisition programs. The full-scale development of an MITL weapon system would not address current USAF PCS requirements.

If the USAF continues with its current strategy which focuses on autonomous weapons, at a minimum it should incorporate an MITL capability or P3I into any LOCAAS-like weapon selected from the MMC acquisition program. This MITL capability will reduce the risk associated with autonomous seeker technology and increase the flexibility of the weapon systems. If the addition of an MITL capability is cost-prohibitive, a cost-saving strategy may be to acquire only the resources (i.e., seekers and data-link equipment) needed to provide this capability to only 10 or 20 percent of the LOCAAS-like weapon inventory.

During the next 10 years, the USAF will be called upon to provide a PCS capability against mobile targets in a high-risk collateral damage environment. Presently, and in the near term, the only weapon system that can provide an operational precision capability in a high-risk collateral damage environment within two to three years is an "improved" data-link MITL-guidance standoff weapon that overcomes current MITL-guidance weapon limitations. Future sensor and guidance technologies must be pursued. However, to meet today's operational shortfalls in PCS operations, resources must be invested in weapon systems that will quickly provide the USAF with a PCS capability against mobile targets.

The USAF's basic doctrinal manual, AFDD 1, states, "Air and space power is providing the 'scalpel' of joint service operations—the ability to forgo the brute force-on-force tactics of previous wars and apply discriminate force precisely where required."³ If precision engagement is going to continue to be a critical part of USAF doctrine and if recent airpower operations are indicative of future airpower employment, the USAF must acquire a PCS capability against mobile targets that enables airpower to achieve political and military objectives in a manner appropriate to the strategic environment. If the USAF fails to acquire a PCS capability against mobile targets in the near term, it may be repeating past mistakes and placing itself in a precarious situation where ". . . doctrine had far outrun the capability to implement it."⁴

Notes

1. John D. Morrocco, "PGM Strategy Faces Budget, Technical Traps," *Aviation Week and Space Technology*, 27 February 1995, 45.

2. Ibid.

3. Air Force Doctrine Document 1, *Air Force Basic Doctrine*, September 1997, 30.

4. Air Vice-Marshal Tony Mason, *Air Power: A Centennial Appraisal* (London: Brassey's, 1994), 103.

Glossary

AFA	Air Force Association
AFDD	Air Force Doctrine Document
AGM	air-to-ground missile
AMM	autonomous miniaturized munition
AMSTE	affordable moving target engagement
ASARS	Advanced Synthetic Aperture Radar System
ATA	automatic target acquisition
ATACMS	Army Tactical Missile System
ATD	advanced technology demonstration
ATR	automatic target recognition
BAT	Brilliant anti-armor submunition
BDA	battle damage assessment
BLU	bomb series designator
CAF	Combat Air Force
CALCAM	conventional air-launched cruise missile
CAOC	Combined Air Operations Center
CBU	cluster bomb unit
CDR	critical design review
CEM	combined effects munitions
CEP	circular error probability
CLAMS	Complementary LADAR/MMW Seeker
DMPI	desired mean point of impact
DOD	Department of Defense
EMD	engineering and manufacturing development
EO	electro-optical
FLIR	forward-looking infrared
FOR	field of regard
FOV	field of view
FPA	focal plane array
FRY	Federal Republic of Yugoslavia
FTMM	fixed-target miniature munition
GBU	guided bomb unit
GCU	guidance control unit
GMTI	ground-moving target indicating
GPS	Global Positioning System
GW	global war
HRC	high-end regional competitor
IIR	imaging infrared
INS	inertial navigation system
INU	inertial navigation unit
IR	infrared
JAOA	Joint Analysis of Alternatives
JASSM	joint air-to-surface standoff missile
JDAM	joint direct attack munition
JSOW	joint standoff weapon
JSTARS	joint surveillance, target attack radar system
LADAR	laser radar

LANTIRN	low altitude navigation target identification
LGB	laser-guided bomb
LOCAAS	Low Cost Autonomous Attack System
LOS	line of sight
LRC	low-end regional competitor
MITL	man in the loop
MK	bomb series designator
MLRS	multiple launch rocket system
MMC	miniaturized munitions capability
MMW	millimeter wave
MNS	mission need statement
MOOTW	military operations other than war
MOP	measures of performance
MSTAR	moving and stationary target acquisition and recognition
MTE	moving target exploitation
MTI	moving target indicator
MTMM	mobile target miniature munition
MTW	major theater war
NATO	North Atlantic Treaty Organization
NM	nautical mile
NSS	national security strategy
P3I	preplanned product improvement
PCS	precision conventional strike
PDRR	program definition and risk reduction
PGM	precision-guided munition
PIP	product improvement program
R&D	research and development
RF	radio frequency
ROE	rules of engagement
S&T	science and technology
SAR	synthetic aperture radar
SFW	sensor fused weapon
SSA	system of systems approach
SSC	small-scale conflict
TESAR	Tactical Endurance Synthetic Aperture Radar
TLE	target location error
TLU	target location uncertainty
TMD	tactical munition dispenser
UAV	unmanned aerial vehicle
UCAV	uninhabited combat aerial vehicle
UN	United Nations
USAF	United States Air Force
VID	visually identify
WAS	wide area surveillance
WCMD	wind corrected munition dispenser

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